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OHIO RIVER POLLUTION CONTROL

LETTER

FROM

THE ACTING SECRETARY OF WAR

TRANSMITTING

A LETTER FROM THE CHIEF OF ENGINEERS, UNITED STATES ARMY, DATED MAY 4, 1943, FORWARDING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, ON A SURVEY OF THE OHIO RIVER AND ITS TRIBUTARIES FOR POLLUTION CONTROL, AUTHORIZED BY SECTION 5 OF THE RIVER AND HARBOR ACT APPROVED AUGUST 26, 1937

IN TWO PARTS
(Three Volumes)

SUPPLEMENTS TO PART TWO

REPORT OF THE UNITED STATES PUBLIC HEALTH SERVICE

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WASHINGTON, D. C., U. S. A.

AUGUST 27, 1943.—Referred to the Committee on Rivers and Harbors and ordered to be printed, with 257 illustrations

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U.S. Ohio river committee

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SUPPLEMENT A

COLLECTION OF DATA ON SOURCES OF POLLUTION

CONTENTS

COLLECTION OF DATA ON SOURCES OF POLLUTION

Introduction

The collection of information on sources of pollution was carried out as part of the assignment of the Office of Stream Sanitation, under the direction of Sanitary Engineer Director H. R. Crohurst, officer in charge. The office was also charged with the preparation of the interim report and later the Final Report of the Ohio River Pollution Survey. This latter work was carried out with able assistance from both pollution survey and regular staffs of the stream pollution investigations station and from the office of the division engineer, Ohio River Division, Corps of Engineers, United States Army. Personnel of the Office of Stream Sanitation detailed to the work are listed, with their specific assignments, in appendix VI of this supplement.

Data on sources of pollution were obtained by engineers working at, and out of, 11 field stations maintained for varying periods of time in the offices of State health departments and of the Tennessee Valley Authority. Available information has been supplemented by information on water supply, sewage disposal, and the effects of pollution, collected during actual field surveys in the many communities on the watershed under study. Visits to industrial establishments were made and data on industrial waste pollution were collected. In all instances, cooperation on the part of municipal officials has expedited the collection of field data. In the industrial surveys the information has been considered confidential, with the understanding that the data received would not be used to the detriment of any particular plant or published independently to reveal process, kinds, and amounts of raw or finished products. Under this agreement, cooperation on the part of industry has generally been received. Surveys were made of some 3,700 municipalities and 1,800 industrial plants.

Special studies of industrial wastes were made in cooperation with the cities of Cincinnati and Louisville, the State of West Virginia, and the Tennessee Valley Authority. These studies were of value, not only in showing the character and amount of wastes discharged at the plants studied but also in estimating the effect of wastes from similar plants elsewhere in the basin where less detailed information was available. Correlated work included the preparation of industrial waste Guides containing information on industrial plant processes and practices, the quantities and strength of wastes for representative plants, waste treatment and recovery practices and their effectiveness in reducing pollution, and a study of the cost of construction and operation of waste-treatment plants both for municipal and industrial wastes. The industrial waste guides have been made the subject of a separate supplement D.

A special field unit surveyed the acid mine drainage problem and determined the amount and distribution of this type of waste and the

damage resulting. A presentation and analysis of this information has been made the subject of a special section of the Final Report of the Ohio River Pollution Survey and of a separate supplement C.

Acknowledgments

The various State health departments of the Ohio River Basin have rendered invaluable help to this survey by making available the results of their years of experience in pollution-abatement work, by furnishing office space to field engineers and by assisting in many other ways. The Health and Safety Section of the Tennessee Valley Authority has aided similarly by furnishing office space, and the results of its investigations of the streams and waste discharges in the Tennessee River Basin. Municipal officials, water and sewage treatment plant operators, and industrial officials have aided by furnishing data on waste discharges and plant operation. The cities of Cincinnati and Louisville have assisted by making available the results of consulting engineers' studies of their waste-treatment problems. Among the Federal agencies that have assisted are the United States Geological Survey, which furnished maps and data on stream flow, the Bureau of the Census, which furnished data on population, the United States Bureau of Mines which aided in the study of acid mine drainage, and the National Resources Planning Board which made available the results of its studies of the Ohio River Basin. In the preparation and criticism of industrial waste guides, assistance has been received from State, Federal, municipal, and industrial officials throughout the country and from consulting engineers, equipment manufacturers, trade associations, universities, and technical schools.

Instructions to Field Engineers

In a survey of the magnitude of the Ohio River pollution survey, using numerous (23 maximum) field engineers, more elaborate procedures are necessary to assure uniformity of results than would be the case in a survey covering a smaller or less populous area. Field surveys of approximately 5,500 municipalities and industries are involved, not including many communities and industries visited and found to be contributing no wastes of consequence.

A detailed manual of instructions was prepared and supervised training trips were taken with the eight engineers assigned during 1939 to field duty. Supplementary instructions were issued from time to time and careful checks were made of the initial reports submitted by the field engineers.

During 1940 the field staff was greatly expanded and the 1939 field engineers were used as officers in charge of field stations with the responsibility of training the new personnel. A revised manual of instructions was prepared incorporating all instructions in the original manual and supplements issued during 1939.

Miscellaneous assistance was furnished the field engineers by the Cincinnati office in the form of detailed maps, river mileages, list of municipalities, preliminary lists of industrial plants, and various forms for note taking and for reporting. The industrial waste guides, although not all available early in the survey, were of considerable assistance in familiarizing the field engineers with industrial

processes, terminology, and particular points of interest from a pollution standpoint. However, municipal water-supply and sewerage-reporting forms and industrial wastes note-taking forms were available from the beginning so that relatively uniform information was collected throughout the survey.

Memoranda and Forms

A total of seven memoranda were furnished, of which the last three or Nos. 5, 6, and 7 are reproduced as appendixes to this supplement. Copies of survey forms and sample reports are also reproduced as an appendix. The individual memoranda are as follows:

Memorandum No. 1.—Manual for Public Health Engineers on Field Duty with State Health Departments, December 29, 1938. This memorandum was supplemented by memorandum No. 3 and other communications and later, in April 1940, was superseded by memorandum No. 5.

Memorandum No. 2.—Instructions Concerning Travel for Field Personnel, Expense Accounts, Reports to Central Office and Miscellaneous Matters. This memorandum deals with matters chiefly administrative in character.

Memorandum No. 3.—Revised Manual for Public Health Engineers on Field Duty With State Health Departments, March 1939. This memorandum supplemented memorandum No. 1 and later, in April 1940, was superseded by memorandum No. 5.

Memorandum No. 4.—River Mileage Index System, April 1939. This memorandum was supplemented and later, in June 1941, was superseded by memorandum No. 6.

Memorandum No. 5.—1940 Manual for Public Health Engineers on Field Duty with State Health Departments, April 1940. This memorandum, representing instructions prepared after experience in supervising field engineers for over a year is reproduced as appendix I of this supplement.

Memorandum No. 6.—River Mileage Index System, June 1940. This is a revision of memorandum No. 4 prepared in the light of experience, using the index system as originally planned and is reproduced as appendix II of this supplement.

Memorandum No. 7.—Damage to Industry by Acid Mine Drainage, September 1940. This memorandum on a special problem is reproduced as appendix III of this supplement.

Survey forms and reports.—Municipal water supply, sewerage, and industrial waste note taking and report forms and sample reports are reproduced as appendix IV of this supplement.

APPENDIX I

MEMORANDUM No. 5 (APRIL 1940)

1940 MANUAL FOR PUBLIC HEALTH ENGINEERS ON FIELD DUTY WITH STATE HEALTH DEPARTMENTS

CONTENTS

INTRODUCTION

This memorandum is a revision of memoranda Nos. 1 and 3 dated December 29, 1938, and February 25, 1939, respectively, outlining the general character of the work being undertaken by each of the cooperating agencies engaged in the Ohio River pollution survey, and methods of making field survey. Experience gained during the first year of the work has indicated the advisability of some changes in survey methods. This memorandum is intended to acquaint the new field engineers with the objectives of the survey, the methods used, and the progress to date and to explain changes in methods to the engineers now on duty.

Section 5 of the River and Harbor Act, approved August 26, 1937, states—

> "that the Secretary of War is hereby authorized and directed to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited, directly or indirectly, therein and the sources and extent of such deposits, and with a view of determining the most feasible method of correcting and eliminating the pollution of these streams. The survey herein authorized shall include comprehensive investigations and studies of the various problems relating to stream pollution and abatement. In making these investigations and studies and in the development and formulation of corrective plans, the Secretary of War may, with the approval of the Secretary of the Treasury, secure the cooperation and assistance of the Public Health Service and may allot funds from the appropriation hereinafter designated to pay for such cooperation and assistance."

At the request of the Secretary of War, the Secretary of the Treasury has authorized the Public Health Service to undertake the following parts of the study:

1. Necessary laboratory examinations.
2. Collection of data on sources of pollution.
3. Determination of the character of water in the main and tributary streams.
4. Determination of the extent and cost of treatment required.
5. All other necessary studies to determine existing and future conditions bearing on pollution.

At the suggestion of the President, a three-man board was appointed to direct the survey. This includes a representative of the Corps of Engineers (Brig. Gen. Max C. Tyler succeeded by Maj. Gen. T. M. Robins), a representative of the Health Service (Sanitary Enginer Director Ralph E. Tarbett) and a non-Government expert (Dr. Abel Wolman).

ORGANIZATION

HYDROMETRIC DATA

The Corps of Engineers possess the best facilities for measuring stream flows, has access to records of stream flow extending over a long period of years and has cooperative relationships with the United States Geological Survey for efficiently obtaining this essential hydrometric data. The Ohio River Division Office of the Engineer Corps is located at Cincinnati, Ohio, and the district offices are at Pittsburgh, Pa., Huntington, W. Va., Cincinnati, Ohio, Louisville, Ky., and Nashville, Tenn. The Corps of Engineers is collecting and tabulating all necessary hydrometric data.

LABORATORY EXAMINATIONS

The stream pollution investigations station of the Public Health Service is making the necessary laboratory examinations of water. Laboratory examinations have been made during 1939 at the Public Health Service station at Cincinnati, Ohio, at the floating laboratory installed on the United States Army Engineer quarterboat, the *Kiski*, and at two mobile laboratories in automobile trailers which did most of the laboratory work on tributary streams. During 1940 the upper and lower thirds of the Ohio Basin will be covered. Three more trailers are being outfitted to aid in this work. Since the Cincinnati laboratory will not be centrally located for the 1940 work the personnel at that station will be transferred to the *Kiski*.

The principal tests made are for coliform bacteria numbers, dissolved oxygen content and biochemical oxygen demand. In addition, tests are made for turbidity, alkalinity or acidity, hardness, suspended and volatile matter, and nitrites. Other tests are made in special cases, particularly where industrial wastes containing objectionable chemical constituents are discharged to the stream. The biological studies of the principal streams are included and during 1940 some special surveys of fish life may be undertaken. An epidemiological survey of gastroenteritis, suspected of being of water-borne origin is being made.

SOURCES OF POLLUTION

The Office of Stream Sanitation, is collecting data on sources of pollution by sewage and industrial wastes on the main river and tributary streams within the basin. The method of collecting the data is briefly as follows:

1. Field engineers are assigned to cooperate with the health departments of the States in the basin.
2. The engineers submit reports on water supply and sewerage facilities and on industrial wastes on forms prepared especially for the purpose.
3. Data in the files of the State health departments are used to as great an extent as possible and these data are supplemented by information obtained by visiting the municipalities and industrial plants.

Details of the methods used are discussed elsewhere in the memorandum.

During 1939 eight assistant public-health engineers have been in the field. Two men have been attached to each of three State health departments, Kentucky, Ohio, and West Virginia; one has been with the Tennessee Health Department and one with the Sanitation Division of the Tennessee Valley Authority. The men in Kentucky and West Virginia have worked also in the sections of Virginia and North Carolina included in the Kanawha and Big Sandy Basins. The men with the Ohio health department have covered the Indiana portion as well as the Ohio portion of the 1939 study area. In general, one of the men in each State covered water supply and sewerage systems and the other surveyed industrial plants discharging wastes.

The man with the Tennessee Health Department covered both fields in the Cumberland Basin in Tennessee and is now surveying the Kentucky section of that basin. The man with the Tennessee Valley Authority has surveyed industrial plants in the Tennessee Basin and assisted in special studies of various industrial wastes. Laboratory surveys have been made on both the Tennessee

and Cumberland Rivers in the past few years by the Tennessee Valley Authority and the Tennessee Health Department respectively, so relatively little additional laboratory work will be necessary to complete the picture.

The Works Progress Administration, working in cooperation with the United States Public Health Service, is carrying on a comprehensive program of sealing abandoned coal mines in eight States, which have bituminous coal mining areas within the Ohio Basin.

Regional offices of the Public Health Service for supervision of mine-sealing programs are located at the following points:

(1) Pittsburgh, Pa.
(2) Huntington, W. Va.
(3) Vincennes, Ind.
(4) Chattanooga, Tenn.

Inasmuch as the Works Progress Administration and the supervisory organization of the Public Health Service on sealing abandoned coal mines are assembling information on the total acid load for each watershed, it will not be necessary for the field workers from this office to obtain quantitative data on this type of industrial waste pollution.

Other Cooperating Agencies

The Bureau of Fisheries, by utilizing its own mobile laboratory, may undertake studies on the effects of certain sewage disposal and industrial wastes disposal practices, on the aquatic life in the Ohio River and possibly in certain selected tributaries. This agency has loaned two boats to the survey which are being used for sample collections on the Ohio River.

Drainage basin committee reports of the National Resources Committee for the following 11 subdrainage basins in the Ohio Basin have been published in the document, Drainage Basin Problems and Programs:

1. Upper Ohio Basin.
2. Beaver Basin.
3. Kanawha Basin.
4. Muskingum-Hocking Basin.
5. Scioto Basin.
6. Miami Basin.
7. Big Sandy-Guyandot Basin.
8. Kentucky-Licking Basin.
9. Green Basin.
10. Wabash Basin.
11. Lower Ohio Basin.

These reports are available and should be read by the field engineers.

Procedure in Making Sources of Pollution Survey

Field surveys of the Public Health Service are conducted in close cooperation with the State health departments concerned. In the present pollution survey the cooperative effort between Federal and State health departments will be continued. The various States are making available to the Public Health Service a vast amount of information which they have collected for their own use. The maintenance of a cordial relationship between the Public Health Service and the State health departments is very important.

The field engineer should keep constantly in mind that he should conduct himself in conformity with the standards, customs, and procedures of the sanitary engineering division of that State health department with which he is cooperating. In this way he can best secure the data on the various aspects of stream pollution and at the same time be of definite assistance to the health department in advancing its program of pollution abatement. As a matter of policy, office hours of field engineers when at their official station should conform to the hours of the cooperating agency. Regular working hours in the field are usually not possible. However, when working with any other State agency, city or industrial plant, work should not be discontinued prior to the local official closing hour unless the particular assignment has been completed.

Water Supply and Sewerage Survey

A. Purpose

Investigation of municipal water supplies, sewerage systems, and sewage-disposal methods of the Ohio River pollution survey are primarily for the purpose of—

(1) Determining the extent surface streams are required as a source of water supply, location of surface water intakes, and the effect of waste pollution on the use of such sources, and

(2) Ascertaining what pollutive substances from municipalities are being discharged directly or indirectly into surface streams, and the sources, extent, and condition of such discharges, and

(3) Providing physical background data essential to formulating the most feasible corrective and control measures.

B. SCOPE

In general, survey data should include all municipalities with public water supplies distributed under pressure, and for water-carried sewage systems. In addition, concise forms are provided for incorporated communities without water or sewage systems. Communities receiving water supplies from adjacent cities or discharging sewage to adjacent systems should be reported individually, with proper reference to the connections in question.

C. METHODS OF SURVEY

(1) *General.*

The field engineer should keep in mind that the primary purpose of the survey is to ascertain what pollutive substances are being discharged directly or indirectly into surface waters of the basin, the sources, and extent, and effects of such discharges, and with a view of determining the most feasible method of correcting and controlling the pollution of the streams. It is all important that field surveys reflect the influences of pollution on normal surface-water uses.

For uniformity and consistency of information from various basins, field reports are submitted on specially prepared forms, devised to include a clear perspective of water and sewerage development at each municipality.

A considerable amount of required data are available from records of State health departments. However, in many instances, field inspections are necessary to supplement and bring these data up to date. Field contacts with municipalities are made through the State health departments. In this manner the established State-municipal relations are not disrupted and the field engineer is able to secure the required information from the proper municipal authorities with minimum delay.

Where underground waters are used as a source of supply, field information is primarily to determine the adequacy and dependability of such sources, and the probability of surface waters having to be used in lieu of, or to supplement, underground supplies.

Where surface waters are used as a source of public supply, the field data should be in more detail to reflect dependability, location of intakes, sources of pollution affecting such locations, treatment practices, and raw-water quality as affected by waste pollution.

Field data on municipal sewerage systems should include the amount, type, and strength of such waste, together with points and condition of discharges. Where sewage treatment facilities are provided, design and operating data should be obtained.

(2) *Field report forms.*

(*a*) *General.*—Two forms, W–1 and W–2 for water-supply reports, two forms, S–1 and S–2 for sewerage reports, and one form WaS–1 are attached. The latter form is used only for reports on towns without water supply or sewerage systems. The other forms are used in all other cases. Forms W–1, S–1, and WaS–1 have spaces for the mileage index number of the town. This number, which serves to locate the town with respect to the streams, is explained in memorandum No. 4. The main watershed referred to on the forms is one of the 22 large divisions of the Ohio Basin. The subwatershed is the stream (or streams in ascending order) by which drainage from the town reaches the main tributary. Other items found on more than one form are those for State, county, municipality, population 1930 and 1940, and source of data. The first three of these need no explanation. Tables showing lists of incorporated places by basins and their 1930 populations will be furnished. If 1940 census populations are available locally they should be included. If not, and an estimate of the 1940 population is made, the fact should be noted. Opposite "Source of data" should be included the name and position of the informant. If the information comes from the files of the State health department, this should be stated.

(*b*) *Water supply* (*Form W–1*).—Source of supply: State whether from dug, drilled, or driven well, spring, infiltration gallery, mine, impounding reservoir, surface stream, or a combination of more than one source. If from a stream give the name of the stream. If the town is served by a supply from another town, this should be stated.

Population served: State the total population served by the supply in the town being reported on and in areas on which no other reports are made. Do not include population served in other towns on which W–1 reports are made. It will be necessary to estimate these figures in many cases. Great accuracy is neither needed nor expected.

Average consumption: This figure should be on the same basis as the population served. Record to closest 10,000 gallons if less than 1,000,000 gallons per day and to the closest 100,000 gallons if more than 1,000,000 gallons per day

Ownership: Municipal or, if private, the name of the company. A few State-, Federal-, county-, and district-owned supplies will be found.

Principal features of treatment: Such as coagulated, settled, filtered, chlorinated, or lime-soda softened.

Location of intakes: Necessary only on surface water supplies. Refer the location to some object which can be located on map such as the mouth of a stream, a bridge, a dam, the city limits, etc.

Remarks: Use this space and, if necessary, additional sheets of paper to explain any figures or information given above which may require explanation. (Use asterisk after outline data to indicate further information in "Remarks.") Give any general information or unusual facts about the supply and treatment, its adequacy, dependability, quality, and the principal difficulties. If important, the effect of sewage, industrial wastes, and mine drainage on surface water supplies should be discussed. This is a survey of pollution and the water supply reports are of secondary importance. More complete information is desirable on surface water supplies than on underground supplies. Indications of future need of surface water supplies because of ground water depletion or for other reasons should be mentioned. More complete reports should be made on large supplies than on small ones.

(*Form W–2*).—This form is used only at towns having surface water supplies under competent laboratory control. Information on coliform organism counts in the raw water is particularly important. Unless laboratory data indicative of the sanitary quality of the raw water are available do not fill out W–2 forms merely to show such data as volume of water, turbidity, hardness, etc. Such information can be summarized under "Remarks" on W–1. A record of about 5 years' laboratory data should be included if available. In recording coliform organism counts it should be noted whether the figures represent most probable numbers or a coliform index.

(*c*) *Sewerage and sewage treatment* (*Form S–1*).—Type system: Such as sanitary, combined, private sewers, misused storm sewers.

Average sewage flow: Will be an estimate in most cases. Record to closest 10.000 gallons if less than 1,000,000 gallons per day and to closest 100,000 gallons if more than 1,000,000 gallons per day.

Number of outfalls: If not readily available, an estimate will suffice.

Receiving stream: If discharge is to more than one stream, the names should be noted with estimated percent of waste to each.

Population accessible to sewers: Will be an estimate in most cases. Record to closest 100 if less than 10,000 and to closest 1,000 if more than 10,000.

Population connected: Similar to population accessible.

Principal features of treatment: Such as Imhoff tanks, trickling filters, secondary settling, disinfection (summer only).

Population connected to treatment plant: Important where not all sewered population is served by treatment plants.

Year installed: Refers to treatment plant.

Rate capacity: Based on smallest unit.

Design population: No explanation necessary.

Remarks: Use this space and, if necessary, additional sheets to explain any figures or information given above which may require explanation. (Use asterisk after outline data to indicate further information in "Remarks.") Discuss any unique features which are of importance. If one is available include a map of the city showing the sewered areas, outfalls, water intakes, etc. Discuss any proposed improvements and include cost estimates, if possible.

If the town has a sewage treatment plant and good laboratory records are available, industrial waste surveys will not be made. In such cases, note briefly what industrial wastes are treated.

Note presence or absence of sludge banks or other visual evidence of pollution. Do nuisance conditions exist at times of low flow, have complaints been made, or lawsuits filed? Discuss local recreation at present and whether stream would be suitable for recreation if pollution were abated. Give any information available

regarding fish and other aquatic life and whether pollution is affecting them. If surveys or studies of pollution have been made include a copy of the report, if possible, or summarize the findings.

(*Form S–2*).—This form is for use only where the town has a sewage treatment plant with laboratory records. Include records of several years operation if possible. Any changes in the plant or notable changes in industrial wastes treated at the plant during the period and any factors which would make the results not representative of present conditions should be noted under "Remarks" on form S–1.

(*Form WaS–1*).—This form is used only for towns with neither water supply nor sewer systems. The headings are self-explanatory.

Industrial Survey

A. PURPOSE

The purpose of entering an industrial plant is to obtain as complete information concerning the plant and the industrial wastes discharged as is possible without detailed study. Data on past and present operation, and the management's idea of future plans and probable growth is of value. More specific purposes served by the collection of this data are: (1) to provide a basis for converting the wastes into population equivalent in terms of biochemical oxygen demand, suspended solids or other quantity units which may be adopted; and (2) to assist in the determination of remedial measures and their costs. Information on industrial waste treatment or pollution remedial measures within the plant is particularly important not only in evaluating wastes from the particular plant but also in adding to information on the subject of correction of industrial waste pollution.

B. SCOPE

As a general policy, all industries discharging obnoxious wastes of consequence into a stream should be investigated.

Industrial plants discharging to municipal sewers which are served by municipal treatment plants need not be investigated where adequate analytical data at the treatment plant are available. Where analytical results are not available or not adequate to enable loadings to be calculated, the industrial plants should be visited. Where such plants are visited, a short note such as "tributary to municipal treatment plant" should be inserted at the top of the first report page and a similar statement should be placed under "Treatment."

Small industries such as laundries and milk plants conducting a local business in every community need not be considered since the biochemical oxygen demand of municipal sewage is considered to include these minor industries.

C. COLLECTION OF INDUSTRIAL INFORMATION

(*1*) *General.*

The field engineer should keep in mind that a primary purpose of the survey is to obtain information which can be used to determine the loading contributed by the particular source in terms of population equivalent biochemical oxygen demand, suspended solids or other units, and to assist in determining, the type, extent, and cost of remedial measures required.

Many items of information desired have to do with the size of the industrial plant. Measures of size include number of employees, amount of water and raw materials used, amount of product made, and amount of wastes of various kinds. One or more of these measures of size may be used to evaluate the wastes of the particular plant reported. Plant practices in the disposal of concentrated materials are very important factors in the evaluation of the wastes as discharged. Such concentrated materials include skim-milk, buttermilk, and whey at milk plants, slop at distilleries, blood, paunch manure, and grease at packing plants, and skins, cores, cobs, etc., at canneries.

Plant history and forecast of future activities bearing on changes which might affect the amount or character of wastes should be solicited.

(*2*) *Industrial waste guides.*

Preliminary guides have been prepared for the purposes of assisting field personnel and forming the basis for more complete and accurate treatises to be prepared at a later date. To date, nine guides covering the brewing, corn and tomato canning, meat, milk, oil, paper, pulp and tanning industries have been prepared and a byproduct coke guide will be distributed in the near future. It is planned to prepare guides on the distilling, textile, and metal industries.

Guides completed to date cover, in general, the following items:

1. Description of process.
2. Raw materials and product.
3. Quantity of wastes.
4. Recovery practices.
5. Disposal other than to sewer.
6. Sources of wastes.
7. Character of wastes.
8. Treatment.
9. Bibliography.
10. Note taking form.
11. Inspection report.
12. Flow diagram.

These guides, containing material collected from many sources, some of which is not published elsewhere, are expected to be of assistance to field engineers. They are of necessity of a preliminary nature at this time due to limited time and sources of available material. The field engineer through his contacts with the many plants of each type covered in the guides has an excellent opportunity to contribute corrections and supplementary information that will help make the later treatise valuable as an accurate reference and he is urged to do so.

(*3*) *Entering industrial plants.*

State health department instructions relative to entering industrial plants should be followed in all cases.

(*4*) *Plant locations.*

Preliminary lists of plants located in the 1940 survey area are being prepared and will be distributed. The name of plant, location by State, basin, county and municipality, general classification of operation, and in some cases the product or raw material, and number of employees are given. These lists were made from data in the preliminary stream pollution survey report of the Ohio River, dated January 1938, made by the United States Engineer Department. It may be necessary for the field engineer to supplement this list from State, county, local, or other sources to bring it up to date. Milk plants were not included in the preliminary survey list and those of consequence will have to be located by the field engineer from the above sources.

(*5*) *Note-taking forms and supplementary information.*

Note-taking forms have been prepared for miscellaneous plants and 10 classified industries. A sample set of these forms is appended. Forms are intended as a guide and convenience for recording information during the actual inspection. They need not be turned in with the report but should be kept by the field engineer for his original record. The number at the right top corner of the note taking form is the classification number for the type of industrial plant and is the number to be inserted in the same place on the report form.[1]

The note-taking form outlines in general the information to be obtained. Most of the outline topics are self-explanatory. However, the experience gained in using this information has developed several points which require clarification. These, together with pertinent points previouly brought out in other memoranda, will be covered below. The following refers to the various note-taking forms and the report form.

River mileage index number, main, and subwatershed: Refer to memorandum No. 6 for details. Under "Main watershed" and "Sub watershed," list receiving tributaries in order from the main watershed back to the outlet stream.

Plant operation: Report days per week also. For meat plants, report the number of killing days per week or per period of time represented by the reported kill so that daily units may be estimated.

Seasonal variation: For canneries give season dates for each product packed and report (under "Products canned"), whether or not simultaneous packing is done on what products, and for how long.

Water supply: A further break-down should be made where multiple sources are used for any one classification. Where well supplies are used, details of pump, etc., need not be reported. Amount of water, treatment, if any, well and rock depths, if available, will be sufficient.

Raw materials, products: Report normal daily figures, if available, otherwise the most recent figures available, and, in addition, the capacity or maximum

[1] Other classified industries shown on "Map symbols" chart may be recorded on the miscellaneous form but the report should bear the proper class number or letter.

24-hour operating figures. In the case of canneries, the normal daily pack at height of season, simultaneous packing, number of lines, etc., and maximum daily pack as well as seasonal packs should be reported.

Explanatory information on the units of raw materials or production should be given where possible to enable conversion to units for which strength equivalents are available. Examples are average weight of hides, capacity of cans (other than 2's, 2½'s and 10's), bottles, and cases, etc.

Wastes: Report total quantity and as much of a break-down of the components making up this total as possible. Under "Disposal other than water carried," report such items as disposal of cuttings, peelings, etc., in the canning industry; paunch manure, blood, in the meat industry; milk byproducts; distillery slop; brewery grain (mention wet or pressed); and similar items in other industries. Mention any history of spills available. Information should be obtained on present segregation of obnoxious wastes from sanitary sewage and cooling water and if not segregated, the possibilities of making such a segregation. Where wastes are treated, as complete a story as possible under "Treatment" should be given. This is important not only for assigning a treatment factor to the wastes but as a guide to remedial practices. For example, if ponding is practiced, give details so that an estimate of its effect may be made. A statement merely saying that wastes pass through a pond to the stream does not furnish much of a basis on which to estimate a reduction figure. The tabular method of describing industrial waste treatment plants used in the Tomato Guide is recommended. Collection of cost data on treatment or remedial measures within the plant is worthy of effort. Possible sources of cost information are of interest.

Under "Analyses" report any state or local analyses available with date and plant status (flow, production, etc.) at the time. Some of these analyses, though they may seem hopelessly out of date, are valuable in many cases because of the little information available otherwise.

Outlet: Under "Gaging possibilities," a statement of possibilities with a view to any possible future detailed studies consisting of gaging, sampling, and analysis of wastes should be made. Mention any conveniences or difficulties in this connection.

Remarks: Valuable information supplementing the outlined items and other useful information may be placed under this heading. Any condition dealing with industrial water supply or waste not already covered should be included. Individual plant characteristics, procedures or practices affecting wastes which are not typical of the industry are important. Information on past history and future plans with regards to growth or operations which might affect amount or character of wastes may be included here. General conditions in receiving stream complaints, etc., state and local comments, recommendations, etc. should be noted.

In connection with determination of remedial measures, information is needed on conditions which might influence the selection of type of treatment, particularly as regards broad irrigation, ponding. Unless otherwise stated, it will be assumed that reported industries will have space, either their own or nearby, for the usual treatment devices but special mention should be made regarding ponding or broad irrigation possibilities.

Where it appears reasonable for a plant to connect to an existing municipal sewer system, or facilities such as interceptors which would probably be installed in connection with the building of a municipal treatment works, comments on this should be included—together with an approximation of the length of industrial sewer which would have to be laid to reach and qualifying conditions such as pumping, etc. Where such connection would appear unreasonable, a statement to that effect should be included.

Flow diagram: A flow diagram should be prepared for each plant visited with the exception that where a diagram has previously been turned in on a similar plant it may be referred to with any supplementary changes noted to enable it to be used for the plant under consideration. The number of flow diagrams prepared should average at least one for every three industrial plants. Examples of flow diagrams for various types of plants are contained in the industrial waste guides.

D. REPORTS

(*1*) *Detailed reports.*

The industrial waste report submitted to the Cincinnati office should consist of the general "I" form as a first sheet followed by the remainder of the required information in outline form on as many sheets of plain paper as is necessary and the flow diagram.

The note taking form used in the inspection may be used as a guide to the outline presentation. The extent of the information desired is presented on the various note taking forms and in supplementary comments discussed in (5) "Note Taking Forms and Supplementary Information." A sample report is appended herewith.

Reports may be submitted in pencil. Flow diagrams submitted should be neatly drawn so that photostatic copies may be made directly from the sheet submitted. Too much time should not elapse between the actual inspection and and the writing of the report. Completed reports should be submitted to the Cincinnati office as soon as possible. Those submitted up to the last of the month will be credited in the monthly status report.

Normally, after possible editing, four typewritten copies of reports will be made at the Cincinnati office. One of these will be sent to the field engineer; two to the State health department, one for their files and the other, if they so desire, to send to the industry; and the fourth copy to be filed at Cincinnati.

(2) *One-sheet remarks.*

Industrial plants visited and found not to produce wastes of consequence because of the magnitude or nature of their business operations may be mentioned for record of visit by submitting a single sheet noting name, location,[2] type, date of visit and whatever brief remarks necessary to qualify the conclusions. Borderline plants and plants treating wastes of consequence should be given a full report.

E. WATERSHED SUMMARY

Upon completion of each report or possibly of the work in each subwatershed the field engineer should place the designated information on a form summary sheet such as used in the 1939 work. Individual plants can be placed on the summary in the order in which inspections are made. However, upon completion of a main watershed, industries should be numbered for recopying in the Cincinnati office in the following order:

(1) Industries on main stream from mouth to mouth of first tributary in numerical order of mileage index numbers.
(2) Name of tributary including mileage index number of mouth.
(3) Industries on tributary in numerical order of mileage index numbers.
(4) Continue on main stream to mouth of next tributary, etc.

F. MONTHLY STATUS REPORTS

A monthly status report is distributed to the field engineers. It includes a table of the estimated total number of industries in each basin or part of basin by States together with the number of reports completed prior to and during the month reported and the estimated percentage of the total completed.

At the end of each month the field engineer should submit to the Cincinnati office the necessary data to establish the status of detailed reports in the sections under his jurisdiction.

G. SUMMARY

Summarizing the industrial waste survey, the field men should—

I. Complete an inspection at which time he should have—
  (*a*) A completed note taking form.
  (*b*) "Remarks" sufficient to cover the following:
    1. Supplemental water supply or waste information.
    2. Practices not typical of the industry.
    3. Past history and future plans.
    4. Attitude of industry.
    5. Stream conditions, complaints.
    6. State and local recommendations.
    7. Information concerned with remedial (possible proposed) treatment.
  (*c*) Tabular description of industrial waste-treatment works.
  (*d*) Flow diagram (except as before mentioned).

II. Complete and submit as soon as possible a report which should consist of an "I" report form, supplementary sheets, tabular waste-treatment description and flow diagram.

[2] Including basin.

III. Upon completion of each subwatershed prepare a watershed summary tabulation on forms to be furnished.

IV. Submit at the end of each month a table (similar to monthly status report) showing status of work in the sections under his jurisdiction.

Map Symbols

WATER SUPPLY—SYMBOL □

Source of supply
(Above symbol)

Surface—R—river
L—lake
I—impounded.
Ground—W—Well.
S—spring.
M—mine.

Treatment
(Inside symbol)

O—No treatment.
D—Chlorination (disinfection).
I—Iron removal.
Z—Zeolite softened.
L—Lime-soda softened.
F—Coagulated, settled, and filtered.
*—Exceptions not covered. Make note at botton of map.

SEWERAGE—SYMBOL ○

Degree of treatment
(Inside symbol)

O—No treatment.
T—Septic tank.
P—Primary treatment.
C—Chemical precipitation.
S—Secondary treatment.
D—Chlorination (disinfection)
Ds—Chlorination—summer only.
*—Exceptions not covered. Make note at botton of map.

Quantity
(Above symbol)

Show sewage flow in million gallons daily.

INDUSTRIAL WASTES—SYMBOL △

Type of industry
(Above symbol)

1. Brewery.
2. Cannery.
3. Coke.
4. Creamery and milk.
5. Distillery.
6. Oil refinery.
7. Packing house (meat).
8. Paper mill and pulp.
9. Steel mill.
10. Tannery.
11. Textile.
12. Metal plating.
13. Chemical plant.
14. Coal mine drainage (shaded).
15. Oil field (shaded).

M Miscellaneous—make note at bottom of map.
* Numerous industries, list by cities at botton of map.

Treatment
(Inside symbol)

Use same letters listed under sewerage.

APPENDIX II

MEMORANDUM No. 6 (JUNE 1940)

RIVER MILEAGE INDEX SYSTEM

INTRODUCTION

This memorandum is a revision of memorandum No. 4 dated April 1939 covering the subject of the river mileage index system. Revision and additions to the system set forth in the supplement of memorandum No. 4 dated May 13, 1939, and other instructions are incorporated in this memorandum. The principal revision not communicated to the field engineers is to the effect that the system should be carried into the smallest tributaries or to the point being identified.

GENERAL

For the purpose of identifying points on the Ohio River and its tributaries it is common practice to make use of river mileages. In order that field men may have a uniform system for designating locations of cities, sewer outfalls, industrial plants or outfalls, waterworks intakes, dams, river crossings, sampling stations, and the like, an index system involving river mileages has been devised.

MAIN TRIBUTARIES

The index system on the main tributaries involves the use of one or more letters to identify the main tributary basins of the Ohio River combined with a figure which represents the distance in river miles from the mouth of the main tributary at its confluence with the Ohio River. For example, Charleston, W. Va., is located on the Kanawha River 58.4 river miles above its mouth. Its index number would, therefore, be K 58.4.

Table 1 gives the index letter or letters to be used in designating the main tributary basins of the Ohio River, and includes all Ohio River tributary basins more than 1,000 square miles in area. To prevent confusion, where more than one letter is used to designate a main tributary, only the first letter in the river designation is capitalized. For example, Lm represents the Little Miami River.

TABLE 1.—*Ohio River pollution survey: Main tributaries of the Ohio River*

Tributary	Miles to mouth, Ohio River	Index letter	State
Allegheny	981.0	A	Pennsylvania and New York.
Beaver	955.6	B	Pennsylvania and Ohio.
Big Sandy	663.9	Bs	Kentucky, West Virginia, and Virginia.
Cumberland	60.6	C	Kentucky and Tennessee.
Green	196.8	Gr	Do.
Guyandot	675.8	Gy	West Virginia.
Hocking	781.7	H	Ohio.
Kanawha	715.3	K	West Virginia, Virginia, and North Carolina.
Kentucky	435.2	Ky	Kentucky.
Licking	510.8	L	Do.
Little Kanawha	796.4	Lk	West Virginia.
Little Miami	516.9	Lm	Ohio.
Miami	489.9	Mi	Ohio and Indiana.
Monongahela	981.0	Mo	Pennsylvania, West Virginia, and Maryland.
Muskingum	808.8	Mu	Ohio.
Ohio, minor and direct	0–981	O	Kentucky, Illinois, Ohio, West Virginia, and Pennsylvania.
Saline	113.7	Sa	Illinois.
Scioto	624.5	Sc	Ohio.
Salt	351.1	St	Kentucky.
Tennessee	46.5	T	Kentucky, Tennessee, Alabama, Georgia, Mississippi, North Carolina, and Virginia.
Tradewater	107.6	Tr	Kentucky.
Wabash	133.0	W	Indiana and Illinois.

SUBTRIBUTARIES

In applying the system to the branches of the main tributaries, the letter or letters designating the main tributary is retained and another letter or letters added to designate the branch. Points on the New River, a branch of the Kanawha, are designated by the letters KN. The mileage figure used on the branch represents the river mileage from the Ohio River. For example, the town of Claremont, W. Va., is located on the New River 28.1 river miles above its mouth. The mouth of the New River, in turn, is 97.0 river miles from the mouth of the Kanawha River. The town of Claremont, W. Va., is, therefore, 28.1 plus 97.0 or 125.1 miles by river from the Ohio, and its index number would be KN 125.1.

Applying the system further, the town of Talcott is located on the Greenbrier River 16.0 miles from its mouth. The mouth of the Greenbrier River is 64.0 miles above the mouth of the New River which, in turn, is 97.0 miles above the mouth of the Kanawha River. Talcott, is therefore, 177.0 river miles from the mouth of the Kanawha River and its index number would be KNG 177.0. The index system should be carried into the smallest tributaries to the point being identified. Points may be located four or five tributaries back from the main tributary.

MAIN OHIO RIVER

Locations on the Ohio River proper are designated by the letters "OR" or "OL", the second letter indicating the right or left bank of the stream when facing in the direction of the current or toward the mouth.

Mileages on the Ohio River are measured from the mouth. United States Engineers publications state mileages on the Ohio River both from the mouth and from the Point Bridge at Pittsburgh, Pa., the source of the Ohio River, and generally work with the latter figures.

MINOR TRIBUTARIES

River mileage index numbers for municipalities and industries on minor tributaries to the Ohio River should include mileage identification for the mouth of such tributaries. For example, Northup, Ohio, on Raccoon Creek, has index No. OR 704.9–R 9.5. Similarly Bloom, Ohio, on Pine Creek, has index No. OR 634.1–P 29.

MILEAGE TABLES

On the Ohio River, most of the main tributaries and a few of the subtributaries, the United States Engineers have made studies which have included determination of river mileage to key points. These mileages have been taken as official and are presented on river mileage tables. By using these mileages the Ohio River Pollution Survey tables will check United States Engineer data.

MAPS

Watershed and subwatershed maps have been prepared for most of the basins showing mileages at 5-mile intervals. Where possible United States Engineer mileages have been used on these maps and intermediate points determined by interpolation. Where United States Engineer mileages are not available, 5-mile intervals have been determined with a map measure and are sufficiently accurate for purposes of this survey.

WATERSHED SUMMARIES

On watershed summaries, cities should be listed numerically from the mouth in accordance with reference numbers rather than alphabetically. The index numbers of subtributary mouths should be listed numerically with points on the main tributary. Points on the subtributary should be listed immediately following, or before listing the next point on the main tributary above the subtributary mouth.

For purposes of the summary, the index number of a city should be taken from the center of town. Where possible, index numbers of industries should be taken to the industry itself. An exception would be an industry discharging to municipal sewers in which case an index number corresponding to the center of town should be given with the letters "a," "b," etc., to differentiate between the various industries.

APPENDIX III

Memorandum No. 7 (September 1940)

DAMAGE TO INDUSTRY BY ACID MINE DRAINAGE

Certain activities relative to damage caused by acid mine drainage are contemplated in connection with the acid mine drainage assignment of the Ohio River pollution survey. Inasmuch as the regular field engineers are or will be visiting industrial plants in mine-drainage areas, these field men will be expected to collect certain information relative to damage to industry by acid mine drainage.

The time available for completion of the field work is limited and it is not intended, therefore, to place a time-consuming burden of consequence on the field staff. Information to be collected has been confined to that which should be readily available. Continuance of this activity will depend upon experience in obtaining information of value with limited time and effort.

A survey form has been devised (I–14, sample copy attached) to assist the field engineers in collecting the desired information. This form indicates specific information to be collected relative to the neutralization of water supplies and the replacement of tubes in boilers.

There are a great many other types of damage which are of consequence and concerning which specific information may possibly be available. Space has been provided for recording such damages. In general, if an industrial plant has definite knowledge of damage, an estimate of which can be substantiated by readily available data, the information should be recorded. If the damage is intangible or not capable of accurate estimation, a note may be taken but no great time or effort should be expended in securing a figure which at best might be questioned.

A list of damages to industry by acid mine drainage generally considered is given on table 1. Damages by acid mine drainage other than to industry, such as to public water supply, agriculture, recreation, locks and dams, and highway structures, need not be considered by the field engineers.

Table 1.—*Types of damage to industry by acid mine drainage*

I. Water supply (public, industrial,[1] and railroad):
  - A. Increased chemicals.[1]
  - B. Corrosion and decreased life:
    1. Pumps, plumbing and piping.
    2. Boilers.[1]
    3. Condensers and heat exchangers.
    4. Treatment equipment.
  - C. Acid-resisting construction.

II. River structures:
  - A. Bridges and culverts.
  - B. Locks and dams.
  - C. Water turbines.

III. Marine equipment:
  - A. Metal barges.
  - B. Steamboats:
    1. Hulls.
    2. Boilers.
  - C. Other floating equipment.
  - D. Loss of time due to drydocking.

IV. Elimination of industry:
  - A. Textiles.
  - B. Food products.
  - C. Other.

[1] Damage covered specifically by damage to industry form.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–14

DAMAGE TO INDUSTRY BY ACID MINE DRAINAGE

Plant ______________ State ______________ Ref. No ______________

City ______________ County ______________ Main Watershed ______________

Address ______________ Sub-watershed ______________

Informant ______________ Title ______________ Principal Product ______________

WATER SUPPLY (Neutralization only): Source Stream ______________

Gal. per day	*Average*	*Maximum*	*Treatment*
Cooling	________	________	________
Boiler	________	________	________
Other	________	________	________

Chemicals Used:	*Grains per Gal.*	*Pounds per day*	*Pounds per Year*	*Cost per lb.*	*Cost per Year*
Cooling:					
Lime	________	________	________	.005	________
Soda Ash	________	________	________	.015	________
________	________	________	________	________	________
Boiler:					
Lime	________	________	________	.005	________
Soda Ash	________	________	________	.015	________
________	________	________	________	________	________
Other:					
Lime	________	________	________	.005	________
Soda Ash	________	________	________	.015	________
________	________	________	________	________	________

Total excess chemical cost (Neutralization only) ______________ $________

BOILER DAMAGES: Tubes replaced per year A ______________

Normal replacements (With neutral raw water) per year B ______________

Cost per tube C ________ Damage per yr. (A−B) × C ________ $________

OTHER DAMAGES: ______________

A. Nature of Damage ______________

Basis for estimate ______________

______________ Estimate of Damage per year $________

B. Nature of Damage ______________

Basis for estimate ______________

______________ Estimate of Damage per year $________

C. Nature of Damage ______________

Basis for estimate ______________

______________ Estimate of Damage per year $________

TOTAL DAMAGE PER YEAR ______________ $________

REMARKS ______________

9/40 Survey by ______________ Date ______________

APPENDIX IV

SAMPLE REPORTS

Sample Municipal Report

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO W–1

Public Water Supply (*Not an Actual City*)

State: *Indiana.* County: *James.* Mileage Index No. *B1Ma 126.*
Municipality: *Smithton.* Main Watershed: *Black.*
Source of Supply: *Maripas River.* Subwatershed: *Maripas.*
Population (1930): *21,063;* (1940) *22,604.* Served: *22,500.*
Average Consumption: *3.5* M. G. D. Ownership: *Municipal.*
Principal Features of Treatment: *Aerated, Coagulated, Settled, Filtered, Chlorinated.*
Date Treat. Installed: *1914.* Rated Capacity Plant: *12.0* M. G. D.
Location of Intakes: *Maripas River near Graves Landing.*
Source of Data: *State Health Dept., B. D. Congrar, City Engineer.*
Remarks—*For a number of years the State Health Dept. has urged the city to move the water intake upstream to a point above local sources of pollution. The present intake is below sources of sewage and industrial wastes from both Smithton and Bardell (see Bardell Report).*

Water is impounded five miles upstream from the intake at what is known as the Portisan Reservoir. The reservoir has a drainage area of approximately 9 square miles and a capacity of 335 million gallons, which is apparently adequate during prolonged droughts. However, in 1935, the city feared a shortage and installed and used several wells. These were not entirely satisfactory because of excessive hardness and iron, and brought complaints that rural wells were being dried up because of their operation.

About 1.5 g. p. g. of alum is used for coagulation. Lime is also added at times. The filtered water usually has a chlorine residual of between 0.05 and 0.10 p. p. m. The character of the raw water is shown on Form W–2. Bacterial counts of over 25,000 per c. c. have been reported.

Survey by *George Spelvin.* Date: *8–15–40.*

Rev. 4/27/40.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO W–2

Public Water Supply—Raw Surface Water Tests—Monthly Summary

Year: *1939.* State: *Indiana.* City: *Smithton.* Watershed: *Black.*

	Water treated M.G.D.	Turbidity p.p.m.	pH	Hardness p.p.m.	Alkalinity p.p.m.	Coliform Organisms per 100 ml.	Remarks
Jan	3.41	12	7.3	212	107	4,430	Coliform tests are presumptive only.
Feb	3.51	37	6.9	130	45	4,510	
Mar	3.46	43	7.1	125	56	1,960	
Apr	3.25	28	7.1	129	59	1,900	
May	3.35	9	7.5	192	129	7,116	
June	3.46	52	7.3	214	127	1,927	
July	3.52	27	7.5	192	122	5,340	
Aug	3.64	14	7.4	196	131	1,781	
Sept	3.65	8	7.6	241	147	1,000	
Oct	3.79	26	7.3	211	115	2,220	
Nov	3.73	8	7.4	268	149	7,627	
Dec	3.57	6	7.5	268	146	1,930	
Max	3.79	52	7.6	268	149	7,627	Spaces in column used as follows:
Min	3.25	6	6.9	125	45	1,000	Max | Min
Avg	3.53	22	7.3	198	111	3,480	Average

Rev. 4/27/40

Survey by *George Spelvin.* Date *9/1/40.*

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO S–1

SEWERAGE (*Not an Actual City*)

State: *Indiana.* County: *James.* Mileage Index No.: *BlMa 126.*
Municipality: *Smithton.* Pop.: (1930) *21,063;* (1940) *22,604.*
Type System: *Separate* (*See Remarks*). Average Sewage Flow: *2.2* M. G. D.
No. Outfalls: *1.* Receiving Stream: *Balliol Creek.*
Pop. Accessible to Sewers: *22,500.* Population Connected: *22,000.*
Principal Features of Sewage Treatment: *Bar Screen, grit chamber, Imhoff tanks, trickling filters (nozzle distribution), secondary sedimentation, prechlorination, sludge beds (part covered).*
Pop. Connected to Treatment: *22,000.* Yr. Installed: *1929.*
Rated Capacity: *5.4* M. G. D. Design Population: *36,000.*
Source of Data: *State Health Department, B. D. Congrar, City Engineer.*
Installation Cost: Interceptors ------ ------ Treat. Plant ------ ------.
Remarks—*Approximately 5 miles of sewers, principally trunk sewers, have been installed with Federal aid. About 1,000 persons (possibly more) living in an area outside the city limits discharge sewage which enters the river above the water intake. To correct this situation will require a low level sewer and pumping station. Cost of such a project, for an ultimate population of 4,000, has been estimated at $150,000.*

A number of lawsuits have been filed against the city in recent years because of odors from the treatment plant. A number of judgments have been rendered against the city, totaling approximately $10,000. The two most recent ones have been decided in favor of the city. In order to diminish plant odors, equipment for prechlorination of the sewage was installed at a point about 1½ miles above the plant. The plant is approximately two miles north of the city limits. Prior to construction of the existing plant, the city had a plant located just north of the city. The effluent enters Balliol Creek a short distance above its confluence with the Maripas River.

At the time of inspection the plant was operating satisfactorily. The prechlorinating apparatus was in operation and only a slight odor was noticeable in the vicinity of the pumping station at the plant. The receiving stream was discolored by the plant effluent but there was no evidence of sludge deposits nor were there any odors. There was no visual evidence of the wastes in the Maripas River below the mouth of Balliol Creek.

The Maripas is considered a fair fishing stream. It is stocked by the Department of Fisheries. The Sandhurst Reservoir, on the Maripas about 20 miles downstream, is extensively used for all types of water recreation.

The plant has a well equipped laboratory equipped for making all standard control tests. Suspended solids, D. O. and B. O. D. tests made daily on untreated sewage and plant effluent. B. O. D. and D. O. tests made twice weekly since March 1940 on Balliol Creek and Maripas River above and below plant.

Survey by *George Spelvin.* Date: *8–15–40.*

Rev. 4/27/40.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO S–2

Sewage Treatment Plant Records—Monthly Summary

Year: 1939. State: *Indiana.* City: *Smithton.* Main watershed: *Black.* Sub-watershed: *Maripas.*

Mo. (Ave.)	Sewage flow M.G.D.	Suspended solids		Dissolved Oxygen			Biochemical Oxygen Demand				Remarks
		Raw	Final	Stream above	Temp.	Stream below	Raw Sewage	Final Sewage	Stream above	Stream below	
Jan	2.24	223	24				200	26			*Average* 8.1 p. p. m. D. O. in Final.
Feb	3.28	137	24				106	21			9.6 " " " "
Mar	3.37	185	18				182	23			8.3 " " " "
Apr	3.03	159	16				110	11			8.3 " " " "
May	1.99	258	23				225	12			7.2 " " " "
June	2.00	260	29				176	18			4.9 " " " "
July	1.97	280	30				164	18			4.1 " " " "
Aug	1.81	265	29				166	17			3.6 " " " "
Sept	1.65	235	20				214	15			3.5 " " " "
Oct	1.78	240	22				216	14			5.8 " " " "
Nov	1.50	241	34				213	14			7.3 " " " "
Dec	1.69	238	37				203	23			6.7 " " " "
Total	26.31	2,721	306				2,175	212			77.4 " " " "
Avg	2.19	227	25.5				181	17.7			6.45 " " " "
Max	3.37	280	37				225	26			9.6 " " " "
Min	1.50	137	16				106	11			3.5 " " " "

Rev. 4/27/40

Survey by *George Spelvin.* Date: *9–1–40.*

SAMPLE INDUSTRIAL WASTE REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–*3*

INDUSTRIAL WASTES

River Mileage Index No. *K 62.3*

Type of Plant: *Byproduct coke.* State: *W. Va.*
Name of Plant: *Consolidated Coke Co.* (*Not an actual plant.*)
Municipality: *Charleston.* Main Watershed: *Kanawha.*
County: *Kanawha.* Subwatershed ------
Address: *P. O. Box 13, Charleston, W. Va.*
Source of Information: *Mr. John Doe, Superintendent.*
Plant Operation: *168 hrs. p. wk.—365 da. p. yr.*
Employees Av. office 16, plant 330.
Max. office 20, plant 340.
Seasonal Variation: *None.*

(Survey report continued on next page)

Survey by *Howard Blank.* Date: *March 6, 1940.*

Sewered Population Equivalent Computation:
Factors used per ton of coal carbonized per day.
B. O. D.: *15.* Suspended solids ------
Sewered population equivalent* based on B. O. D.: *18,000.*
Sewered population equivalent* based on suspended solids ------
Remarks: *Quench is completely enclosed system.*
Final cooler water not recirculated.
Köppers Vapor recirculation dephenolization system.
Computation by *M. L. Wood.* Date: *4-15-40.* Cincinnati Office.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

*Rounded to nearest 100.

(*Sample industrial waste report continuation sheet*)

Consolidated Coke Co., K 62.3
Charleston, W. Va.

Water Supply—
Drinking: from city mains. Av. 34,600. Max. 36,000 g. p. d.
Industrial: Kanawha River. Av. 500,000. Max. 700,000 g. p. d.
Cooling: Kanawha River. Av. 2.5. Max. 3.0 Mil. g. p. d.

Raw Materials—Coal ---------- 1,200 T. p. d.
Sulphuric Acid (26° Be) ---------- 15.6 T. p. d.
Caustic Soda (95%) ---------- 468 lb. p. d.
Lime ---------- 1,560 lb. p. d.

Products—Coke ---------- 840 T. p. d.
Crude Phenol ---------- 1,000 lb. p. d.
Total ammonium sulphate ---------- 12 T. p. d.
Tar ---------- 9,600 g. p. d.
Xylene ---------- 120 g. p. d.
Benzene ---------- 2,400 g. p. d.
Toluene ---------- 240 g. p. d.

Napthalene is separated in final cooler and added to the crude tar. Crude tar is sold as such and not refined.

Wastes—Total (from metered supply less loss in quenching) ---------- 2.8 mil. g. p. d.
Final Cooler (not recirculated) ---------- 378,000 g. p. d.
Ammonia Still Waste ---------- 26,000 g. p. d.
Benzol Carrying ---------- 18,000 g. p. d.
Quench water lost to atmos ---------- 150,000 g. p. d.
Cooling ---------- 2.46 mil. g. p. d.

Spent sulphuric acid and residue from pure still are dumped on slag pile or burned.

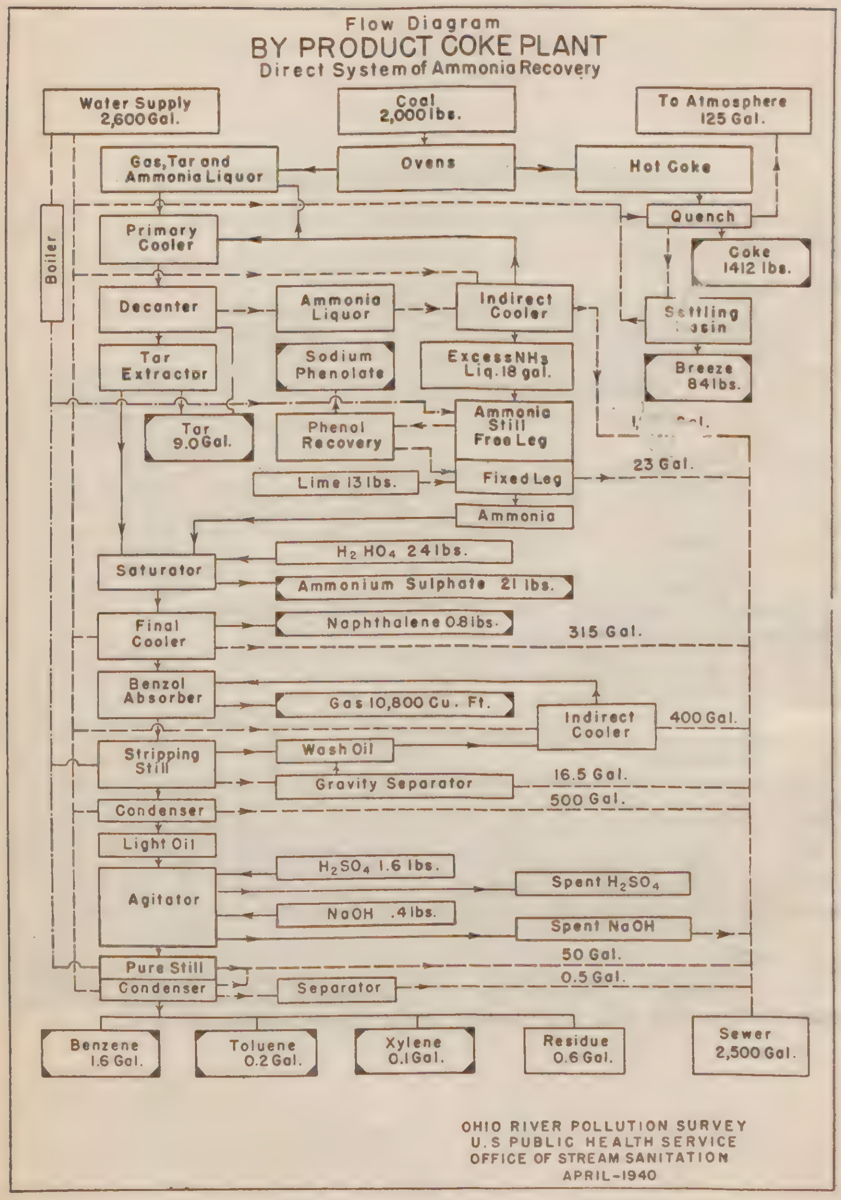
Phenol is recovered as crude phenol by the Koppers Vapor recirculation process.

Analysis—Analyses show an average ammonia liquor phenol content of 3,021 p. p. m. and the ammonia still waste contained 112 p. p. m. A recovery efficiency of 96.5%. Analyses are made daily by plant lab.

Outlets—18″ circular tile at east end of Co. property, carrying cooling water, storm water, and sanitary waste.

2–6″outlets carrying final cooler water, ammonia still waste, and benzol carrying waste, at rear of quench tower and 50′ west of pump house. All may be measured by weirs in channel between outlet and river.

Remarks—Company does not contemplate any immediate expansion.


Flow Diagram
BY PRODUCT COKE PLANT
Direct System of Ammonia Recovery
Water Supply 2,600 Gal.
Coal 2,000 lbs.
To Atmosphere 125 Gal.
Gas, Tar and Ammonia Liquor
Ovens
Hot Coke
Boiler
Quench
Primary Cooler
Coke 1412 lbs.
Decanter
Ammonia Liquor
Indirect Cooler
Tar Extractor
Sodium Phenolate
Excess NH3 Liq. 18 gal.
Breeze 84 lbs.
Tar 9.0 Gal.
Phenol Recovery
Ammonia Still Free Leg
Lime 13 lbs.
Fixed Leg
23 Gal.
Ammonia
Saturator
H2 HO4 24 lbs.
Ammonium Sulphate 21 lbs.
Final Cooler
Naphthalene 0.8 lbs.
315 Gal.
Benzol Absorber
Gas 10,800 Cu. Ft.
Indirect Cooler
400 Gal.
Stripping Still
Wash Oil
Gravity Separator
16.5 Gal.
Condenser
500 Gal.
Light Oil
Agitator
H2SO4 1.6 lbs.
Spent H2SO4
NaOH .4 lbs.
Spent NaOH
50 Gal.
Pure Still
Condenser
Separator
0.5 Gal.
Benzene 1.6 Gal.
Toluene 0.2 Gal.
Xylene 0.1 Gal.
Residue 0.6 Gal.
Sewer 2,500 Gal.
OHIO RIVER POLLUTION SURVEY
U.S PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL-1940

NOTE TAKING FORM

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

BY-PRODUCT COKE PLANT WASTES (Not an actual plant)

Plant Consolidated Coke Co. State W. Va. Ref. No. K 623

City Charleston County Kanawha Main Watershed Kanawha

Address P.O. Box 13, Charleston, W. Va. Sub-watershed ——

Informant Mr. John Doe Title Super Principal Product Coke

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	168	365	330
Maximum	168	365	340

Seasonal variation None

WATER SUPPLY:	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City Supply	34,600	36,000	Coag.-Sed.-Filt.-Chlor.
Industrial	Kanawha R.	500,000	700,000	None
Cooling	Kanawha R.	2.5 Mil.	3.0 Mil.	None

COAL PROCESSED DAILY 1,200 Tons

Chemicals: Sulphuric Acid 15.6 T.-26°Be Sodium Hydroxide 468 lb. Lime 1,560 lb.

PRODUCTS:- Daily Average: Coke 840 Tons ~~Sodium~~ Phenol~~ate~~ 1,000 lb.

Ammonium Sulfate 12 Tons Tar 9,600 gal. Xylene 120 gal. Benzene 2,400 gal.

Toluene 240 gal. Tar (Shipped as such) 100 % (Processed) 0

WASTES:- Quantity 2.8 Mil. gal. p.d. How estimated metered Supply quench

Character: ~~Washing~~ F. Cooler 378,000 gal. p.d. Quenching 150,000 gal. p.d.

Ammonia still waste 26,000 gal. p.d. Cooling and condensing 2.46 Mil. g.p.d.

Carrying benzol 18,000 gal. p.d. Recirculating None

Disposal other than water carried Spent H_2SO_4 & still residue to Slag pile

Possible spills no recent history Type phenol recovery Koppers Vapor Circulat'n

EFFLUENT ANALYSES: Number daily Date — By whom Plant Lab.

P.P.M. Phenol: Ammonia Liquor 3021

Ammonia still wastes 112 Per cent phenol recovered 96.5

OUTLET: Where to Kanawha River

Description:	Size and Shape	Material	Location	Elevation
1.	18" Cir.	Tile	East end	Co. Property line
2.	6" Cir.	Cast iron	Rear of	quench tower
3.	6" Cir.	Tile	50' West of	pump house

Gaging possibilities Good - weir in channel from outlets to River

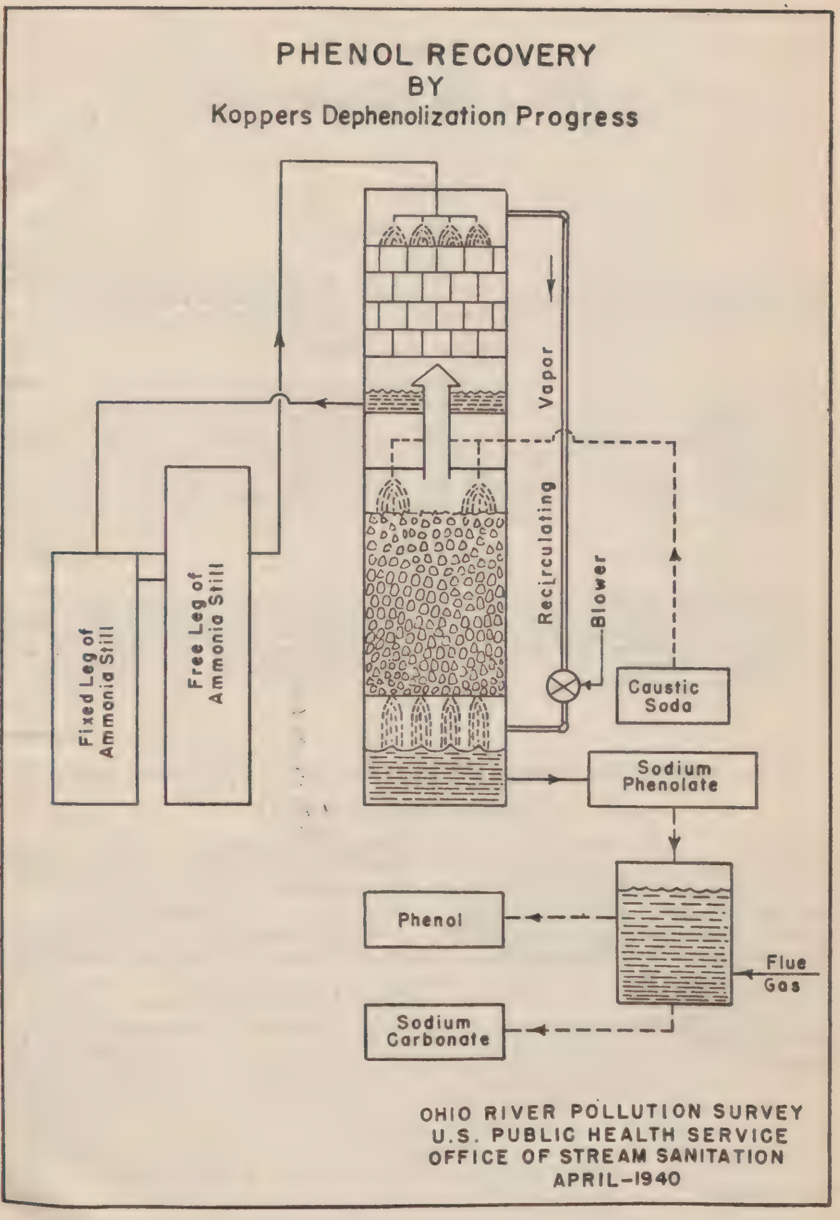
Conditions below outlet: Color Some oils

Turbidity Slight Deposits none

SANITARY SEWAGE: Disposal run to Kanawha Persons tributary 346

REMARKS Quench is completely enclosed Sys. Final cooler water not recirculated. No increase in capacity contemplated.

Survey by Howard Blank Date 3-6-1940


PHENOL RECOVERY
BY
Koppers Dephenolization Progress
Vapor
Recirculating
Blower
Caustic Soda
Sodium Phenolate
Fixed Leg of Ammonia Still
Free Leg of Ammonia Still
Phenol
Sodium Carbonate
Flue Gas
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL–1940

APPENDIX V

SURVEY AND MISCELLANEOUS FORMS

CONTENTS

MUNICIPAL FORMS

INDUSTRIAL WASTE FORMS

MISCELLANEOUS FORMS

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO W-1

PUBLIC WATER SUPPLY

State---------- County-------------- Mileage Index No------------------
Municipality---------------------------- Main Watershed--------------------
Source of Supply---------------------- Subwatershed------------------------
Population (1930)-------------------- (1940)---------- Served--------------
Average Consumption------------ M. G. D. Ownership------------------
Principal Features of Treatment--

Date Treat. Installed------------------ Rated Capacity Plant--------M. G. D.
Location of Intakes---
Source of Data---
Remarks---

Survey by-------------------- Date----------------
Rev. 4/27/40.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO W-2

Public Water Supply—Raw Surface Water Tests—Monthly Summary

Year______ State__________ City________________ Watershed______________

	Water treated M. G. D.	Turbidity p. p. m.	pH	Hardness p. p. m.	Alkalinity p. p. m.	Coliform Organisms per 100 ml.	Remarks
Jan							
Feb							
Mar							
Apr							
May							
June							
July							
Aug							
Sept							
Oct							
Nov							
Dec							
Max							Spaces in column used as follows:
Min							Max | Min
Avg							Average

Rev. 4/27/40 Survey by________________________ Date__________________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO S-1

SEWERAGE

State ________________________________ Mileage Index No. _________________
Municipality _________________________ Pop. (1930) ________ (1940)__________
Type System __________________________ Average Sewage Flow ______ M. G. D.
No. Outfalls__________________________ Receiving Stream __________________
Pop. Accessible to Sewers ____________ Population Connected ______________
Principal Features of Sewage Treatment ___________________________________
____
____
Pop. Connected to Treatment __________________ Yr. Installed ___________
Rated Capacity __________ M. G. D. Design Population __________________
Source of Data ____
Installation Cost: Interceptors ____________ Treat. Plant ________________
Remarks ____
____
____
____
____
Survey by ___________________ Date _______________
Rev. 4/27/40.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO S-2

Sewage Treatment Plant Records—Monthly Summary

Year__________ State________________ City________________ Main watershed________________ Sub-watershed________________

Mo. (Ave)	Sewage flow M. G. D.	Suspended solids		Dissolved oxygen			Biochemical oxygen demand				Remarks
		Raw	Final	Stream above	Temp.	Stream below	Raw Sewage	Final Sewage	Stream above	Stream below	
Jan											
Feb											
Mar											
Apr											
May											
June											
July											
Aug											
Sept											
Oct											
Nov											
Dec											
Total											
Avg											
Max											
Min											

Rev. 4/27/40

Survey by________________ Date________________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO WaS-1

General

COMMUNITIES WITHOUT WATER AND SEWERAGE SYSTEMS

State________________ Main Watershed________________
County________________ Subwatershed________________
Community________________ Pop. (1930)________ (1940)________
Incorp. or Unincorp________________ Informant________________
Water supply (General)________________________________
____
____
Sewage Disposal (Methods)________________________________
____
____
Proposed Water and Sewerage Systems________________________________
____
____
Location Respect Stream, Topography, etc________________________________
____
____
____
____

Survey by________________ Date________________

OHIO RIVER POLUTION SURVEY—U. S P. H. S.—CINCINNATI, OHIO I–

Industrial Wastes

River Mileage Index No.________________
Type of Plant________________ State________________
Name of Plant________________________________
Municipality________________ Main Watershed________________
County________________ Subwatershed________________
Address________________________________
Source of Information________________________________
Plant Operation________________________________
____
____
____
Seasonal Variation________________________________

(Survey report continued on next page)

Survey by________________ Date________________

____

Sewered Population Equivalent Computation:
Factors used
B. O. D________________ Suspended solids________________
Sewered population equivalent* based on B. O. D________________
Sewered population equivalent* based on suspended solids________________
Remarks________________________________
____
____
Computation by________________ Date________________, Cincinnati Office.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

*Rounded to nearest 100.

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–M

INDUSTRIAL WASTES—MISCELLANEOUS

Plant____________________________ State____________ Ref. No___________

City________________ County____________ Main Watershed______________________

Address____________________________________ Sub-watershed______________________

Informant____________________ Title______________ Industry____________

Plant Operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average	____________	____________	____________
Maximum	____________	____________	____________

Seasonal variations____

WATER SUPPLY:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	__________	__________	__________	__________
Industrial	__________	__________	__________	__________
Cooling	__________	__________	__________	__________

RAW MATERIALS:

____

Chemicals____

____

PRODUCTS:

____

WASTES: Quantity______________________ How estimated____________________

Character: Washings______________________ Acid______________________

Process __________________________ Alkali________________________

Disposal other than water carried___________________________________

Possible spills____

Segregation of Strong Wastes_______________________________________

Difficulties____

Treatment ____

Analyses: Number______________ Date______________ By whom____________

Appearance ____

OUTLET: Where to____

Description:	*Size and Shape*	*Material*	*Location*	*Elevation*
1.	__________	__________	__________	__________
2.	__________	__________	__________	__________
3.	__________	__________	__________	__________

Gaging possibilities____

Conditions below outlet: Color_____________________________________

Turbidity ____________________________ Deposits __________________

SANITARY SEWAGE: Disposal____________________Persons tributary_____________

REMARKS ____

____

Rev. 4/40 Survey by_____________________________ Date________________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–1

Brewery Wastes

Plant__________ State__________ Ref. No__________

City__________ County__________ Main Watershed__________

Address__________ Subwatershed__________

Informant__________ Title__________ Principal product__________

Plant Operation:	*Hours Per Week*	*Days per Year*	*Plant Employees*
Average			
Maximum			

Seasonal variation__________

Water Supply:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking				
Industrial				
Cooling				

Raw Materials: Malt__________ Rice__________
Corn__________ Hops__________
Yeast__________ Other__________

Products:	Brews per week:
Beer__________bbl. per brew	Average_____ Maximum_____
__________bbl. per year	Percent of Product Bottled__________

Wastes: Quantity__________ How estimated__________
Brewers grain__________ Disposal__________
Spent Hops__________ Disposal__________
Yeast__________ Disposal__________
Treatment__________
Analyses: Number__________ Date__________ By whom__________
Appearance__________

Outlet: Where to__________

Description:	*Size and shape*	*Material*	*Location*	*Elevation*
1.				
2.				
3.				

Gaging possibilities__________
Conditions below outlet: Color__________
Turbidity__________ Deposits__________
Sanitary Sewage: Disposal__________ Persons tributary__________
Remarks__________
Survey by__________ Date__________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–2

Cannery Wastes

Plant________________________ State______________ Ref. No___________

City__________ County______________ Main Watershed____________________

Address________________________________ Sub-watershed____________________

Informant______________________ Title______________ Principal Product_____________

Plant operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average	________________	________________	________________
Maximum	________________	________________	________________

Seasonal variation____

Water Supply:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	____________	____________	____________	____________
Industrial	____________	____________	____________	____________
Cooling	____________	____________	____________	____________

Products Canned____

____

Normal production, height of season______________________________ per day

Wastes: Quantity______________________________ How estimated______________

Washing____

Other____

____

Disposal other than water carried_______________________________________

____

Possible spills____

Segregation of Strong Wastes____

Difficulties____

Treatment____

Analyses: Number___________ Date___________ By whom_______________

Outlet: Where to____

Description:	*Size and Shape*	*Material*	*Location*	*Elevation*
1.	________________	____________	____________	____________
2.	________________	____________	____________	____________
3.	________________	____________	____________	____________

Gaging possibilities ____

Conditions below outlet: Color____

Turbidity__________________________ Deposits_______________________

Sanitary Sewage: Disposal__________________ Persons tributary____________

Remarks____

____

Rev. 8/39 Survey by______________________________ Date_______________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–3

Byproduct Coke Plant Wastes

Plant________________________________ State___________ Ref. No.__________

City________________ County___________ Main Watershed__________________

Address______________________________ Sub-watershed__________________

Informant______________________ Title______________ Principal Product___________

Plant Operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average	________________	______________	______________
Maximum	________________	______________	______________

Seasonal variation____

Water Supply:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	___________	___________	___________	___________
Industrial	___________	___________	___________	___________
Cooling	___________	___________	___________	___________

Coal Processed Daily____

Chemicals: Sulphuric Acid_________ Sodium Hydroxide________ Lime______

Products: Daily Average: Coke____________ Sodium Phenolate____ _______

Ammonium Sulfate _____ Tar________ Xylene________ Benzene_________

Toluene__________ Tar (Shipped as such)__________ (Processed)_________

Wastes: Quantity__________________ How estimated__________________

Character: Washing________________ Quenching___________________

Ammonia still waste____________ Cooling and condensing____________

Carrying benzol__________________ Recirculating__________________

Disposal other than water carried__________________________________

Possible spills _______________ Type phenol recovery__________________

Effluent Analyses: Number____________ Date__________ By whom_________

P. P. M. Phenol: Ammonia Liquor______________________________________

Ammonia still wastes ____________ Percent phenol recovered_____________

Outlet: Where to____

Description:	*Size and Shape*	*Material*	*Location*	*Elevation*
	1. ________________	___________	___________	___________
	2. ________________	___________	___________	___________
	3. ________________	___________	___________	___________

Gaging possibilities____

Conditions below outlet: Color____

Turbidity__________________________ Deposits ____________________

Sanitary Sewage: Disposal_ _____ _______ Persons tributary_____ _________

Remarks____

____

Survey by____________________________ Date___________________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–4

Milk Plant Wastes

Plant______ State______ Ref. No______

City______ County______ Main Watershed______

Address______ Sub-Watershed______

Informant______ Title______ Principal Product______

Plant Operation:	*Hours per Week*	*Days per year*	*Plant Employees*
Average	______	______	______
Maximum	______	______	______

Seasonal variation______

Water Supply:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	______	______	______	______
Industrial	______	______	______	______
Cooling	______	______	______	______

Raw Materials:	*lbs. per day*		*Milk*	*Cream*
Average	______	______	______	______
Maximum	______	______	______	______

Products: Bottled Milk______ Cream______

Butter______ Cheese______ Whey______

Buttermilk______ Milk powder______

Skim Cond.______ Other______

Wastes: Quantity______ How estimated______

Churn washings______ Pasteurizer washings______

Floor washings______ Sour cream______

Buttermilk______ Whey______

Dryer residue______ Spills______

Disposal other than water carried______

Segregation of Strong Wastes______

Difficulties______

Treatment______

Analyses: Number______ Date______ By whom______

Outlet: Where to______

Description:	*Size and Shape*	*Material*	*Location*	*Elevation*
1.	______	______	______	______
2.	______	______	______	______
3.	______	______	______	______

Gaging possibilities______

Conditions below outlet: Color______

Turbidity______ Deposits______

Sanitary Sewage: Disposal______ Persons tributary______

Remarks______

______

Rev. 8/39 Survey by______ Date______

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–5

DISTILLERY WASTES

Plant__________ State__________ Ref. No.__________

City__________ County__________ Main Watershed__________

Address__________ Sub-watershed __________

Informant __________ Title __________ Principal Product __________

Plant Operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average			
Maximum			

Seasonal variation__________

WATER SUPPLY:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking				
Industrial				
Cooling				

RAW MATERIALS: Corn__________ Rye__________

Malt __________ __________

PRODUCTS: Alcohol__________

Whiskey__________

Other__________

WASTES: Quantity__________ How estimated__________

Beer Slop Quantity__________ Screen Mesh__________

Back Slop__________ Thin Slop__________

Treatment__________

Dryer__________ Rectifying Still__________

Tailings__________ Spills__________

Analyses: Number__________ Date__________ By whom__________

Appearance__________

OUTLET: Where to__________

Description:	*Size and shape*	*Material*	*Location*	*Elevation*
1.				
2.				
3.				

Gaging possibilities__________

Conditions below outlet: Color__________

Turbidity __________ Deposits__________

SANITARY SEWAGE: Disposal__________ Persons tributary__________

REMARKS__________

Rev. 12/40 Survey by__________ Date__________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I-6

OIL REFINERY WASTES

Plant________________________ State__________ Ref. No_________

City______________ County___________ Main Watershed__________________

Address______________________________ Sub-watershed__________________

Informant____________________ Title___________ Principal Product_____________

Plant Operation:	*Hours Per Week*	*Days per Year*	*Plant Employees*
Average	________	________	________
Maximum	________	________	________

Seasonal variation ____

WATER SUPPLY:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	________	________	________	________
Industrial	________	________	________	________
Cooling	________	________	________	________

RAW MATERIALS: Crude oil____

Reclaimed oil______________________ Other______________________

PRODUCTS: Gasoline__________________ Fuel oil____________________

Lub. oil___________________________ Other______________________

WASTES: Quantity___________________ How estimated_______________

Character: Washings________________ Acid_______________________

Process____________________________ Alkali_____________________

Water seal_________________________ Other______________________

Possible spills____

Skimming basin____

____

Analyses: Number___________ Date___________ By whom_________

Appearance____

OUTLET: Where to____

Description:	*Size and shape*	*Material*	*Location*	*Elevation*
1.	________	________	________	________
2.	________	________	________	________
3.	________	________	________	________

Gaging possibilities____

Conditions below outlet: Color___________________________________

Turbidity__________________________ Deposits____________________

SANITARY SEWAGE: Disposal______________ Persons tributary______________

REMARKS____

____

Survey by__________________________ Date_____________________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–7

MEAT INDUSTRY WASTES

Plant ____ State ____ Ref. No ____

City ____ County ____ Main Watershed ____

Address ____ Sub-Watershed ____

Informant ____ Title ____ Principal Product ____

Plant Operation: | *Hours per Week* | *Days per Year* | *Plant Employees*

Average ____

Maximum ____

Seasonal variations ____ Killing days per week ____

WATER SUPPLY: | *Source* | *Av. g. p. d.* | *Max. g. p. d.* | *Treatment*

Drinking ____

Industrial ____

Cooling ____

KILL: Per ____ | *Beef* | *Calves* | *Lambs* | *Hogs*

Normal ____

1938 ____

Maximum ____

If available, give live weights under remarks.

U. S. Inspected? ____ Local Inspection? ____

WASTES: Quantity ____ How estimated ____

Blood recovered ____

Method ____

Paunch Manure ____

Rendering ____

Segregation of Strong Wastes ____

Difficulties ____

Grease traps ____

Other treatment ____

Analyses: Number ____ Date ____ By whom ____

Appearance ____

Stock Pens: Area ____ Stock capacity ____

OUTLET: Where to ____

Description: | *Size and Shape* | *Material* | *Location* | *Elevation*

1. ____

2. ____

3. ____

Gaging possibilities ____

Conditions below outlet: Color ____

Turbidity ____ Deposits ____

SANITARY SEWAGE: Disposal ____ Persons tributary ____

REMARKS ____

Rev. 8/39 Survey by ____ Date ____

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–8

PULP AND PAPER MILL WASTES

Plant________________ State__________ Ref. No__________

City__________ County__________ Main Watershed__________

Address__________________ Sub-watershed__________

Informant__________ Title__________ Principal Product__________

Plant Operation:

	Hours per Week	*Days per year*	*Plant Employees*
Average	________	________	________
Maximum	________	________	________

Season variation ______________________________

WATER SUPPLY:

	Source	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	________	________	________	________
Industrial	________	________	________	________
Cooling	________	________	________	________

RAW MATERIALS: Wood__________ Soda pulp__________
Sulphite pulp__________ Old paper__________
Groundwood pulp__________ Straw__________
Paper shavings__________ Rags__________
Chemicals: Clay__________ Talc__________
Alum__________ Size__________ Soda ash__________
Caustic soda__________ Bleach__________ Dyes__________

PRODUCTS: Capacity in T/day__________ Normal operation__________
____
____

WASTES: Quantity__________ How estimated__________
Character______________________________
____
Disposal other than water carried__________
Dump of stock chest when change colors__________
Possible spills__________
Segregation of Strong Wastes__________
Difficulties__________
Treatment__________ Recovery practices__________
Analyses: Number__________ Date__________ By whom__________
Appearance__________

OUTLET: Where to__________

Description:

	Size and shape	*Material*	*Location*	*Elevation*
1.	________	________	________	________
2.	________	________	________	________
3.	________	________	________	________

Gaging possibilities__________
Conditions below outlet: Color__________
Turbidity__________ Deposits__________

SANITARY SEWAGE: Disposal__________ Persons tributary__________

REMARKS______________________________

Rev. 8/39 Survey by__________ Date__________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–9

STEEL MILL WASTES

Plant__________ State__________ Ref. No.__________

City__________ County__________ Main Watershed__________

Address__________ Sub-watershed__________

Informant__________ Title__________ Principal Product__________

Plant Operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average			
Maximum			

Seasonal variation__________

WATER SUPPLY:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking				
Industrial				
Cooling				

RAW MATERIALS: Short Tons per year: Pig Iron__________

Scrap Iron__________ Other__________

Acids: H_2SO_4__________

HCl __________ Other Acid__________

Alkalis: Lime__________

Soda Ash__________ Other Alkali__________

Alkali Pickling Done?__________

PRODUCTS: Wire & nails__________ Str. Steel__________

Galv__________ Tin plate__________

Other__________

WASTES: Quantity __________ How estimated__________

Pickling __________ Rinsing__________

Alkali __________ Other__________

Possible spills__________

Treatment __________

Analyses: Number__________ Date__________ By whom__________

	% Free H_2SO_4	*% $FeSO_4$*	*or % Fe*
Ave. by wt.			
Pickle Liquor			
Rinse Water			
Indicator			

OUTLET: Where to__________

Description:	*Size and shape*	*Material*	*Location*	*Elevation*
1.				
2.				
3.				

Gaging possibilities__________

Conditions below outlet: Color__________

Turbidity__________ Deposits__________

SANITARY SEWAGE: Disposal__________ Persons tributary__________

REMARKS__________

Rev. 9/40 Survey by__________ Date__________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–10

TANNERY WASTES

Plant ______ State ______ Ref. No. ______

City ______ County ______ Main Watershed ______

Address ______ Sub-watershed ______

Informant ______ Title ______ Principal Product ______

Plant Operation:	*Hours per Week*	*Days per Year*	*Plant Employees*
Average	______	______	______
Maximum	______	______	______

Seasonal variation ______

WATER SUPPLY:	*Source*	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking	______	______	______	______
Industrial	______	______	______	______
Cooling	______	______	______	______

RAW MATERIALS: Raw hides ______

Chemicals: Lime ______ Sulphuric acid ______

Chrome ______ Dye ______

Other ______

PRODUCTS ______

______

WASTES: Quantity ______ How estimated ______

Washings ______ Lime ______

Acid ______ Chrome ______

Dye ______ Other ______

Possible spills ______

Grease trap ______

Analyses: Number ______ Date ______ By whom ______

Appearance ______

Analyses: Number ______ Date ______ By whom ______

OUTLET: Where to ______

Description:	*Size and shape*	*Material*	*Location*	*Elevation*
1.	______	______	______	______
2.	______	______	______	______
3.	______	______	______	______

Gaging possibilities ______

Conditions below outlet: Color ______

Turbidity ______ Deposits ______

SANITARY SEWAGE: Disposal ______ Persons tributary ______

REMARKS ______

Survey by ______ Date ______

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I-11

TEXTILE WASTES

Plant______________ State__________ Ref. No__________

City__________ County__________ Main Watershed__________

Address______________ Sub-watershed__________

Informant__________ Title__________ Principal Product__________

Plant Operation:

	Hours per Week	Days per Year	Plant Employees
Average			
Maximum			

Seasonal variation______________

WATER SUPPLY:

	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial				
Cooling				

RAW MATERIAL: Lbs. per Yr. Cotton______________

Wool: Grease__________ Scoured__________ Substitutes__________

Rayon______________ Silk______________

Chemicals: Soap______________ Oils______________

Dyestuffs______________ Bleach______________

____

PROCESS: Scoured______________ Dyed______________

Bleached______________

PRODUCTS: ______________

____

WASTES: Quantity__________ How estimated__________

Character: Washings______________ Acid__________

Process______________ Alkali__________

Possible spills______________

Segregation of Strong Wastes______________

Difficulties______________

Treatment______________

Analyses: Number__________ Date__________ By whom__________

Appearance______________

OUTLET: Where to______________

Description:

	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities______________

Conditions below outlet: Color______________

Turbidity______________ Deposits______________

SANITARY SEWAGE: Disposal__________ Persons tributary__________

REMARKS______________

Rev. 8/39 Survey by______________ Date__________

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–12

COAL WASHERY WASTES

Plant .... State .... Ref. No ....

City .... County .... Main Watershed ....

Address .... Sub-watershed ....

Informant .... Title ....

Plant Operation:

	Hours per Week	*Days per Year*	*Plant Employees*
Average			
Maximum			

Seasonal variations ....

WATER SUPPLY:

	Source	*Av. g. p. d.*	*Max. g. p. d.*	*Treatment*
Drinking				
Industrial				
Cooling				

RAW COAL ENTERING PLANT DAILY: ....

Fractions: Crushed .... Washed ....

Recovered .... Recrushed ....

Chemicals ....

SULFUR CONTENT: Raw Coal .... Refuse ....

COAL LOADED OR STORED DAILY: ....

WASHING AND PREPARATION PROCESSES: ....

....

Wastes: Quantity .... How estimated ....

Recovery Eff .... Dryer Eff ....

Clean-outs: ....

Disposal other than water carried: ....

....

Spills or Other Wastes ....

Treatment ....

Analyses: Number .... Date .... By whom ....

Appearance ....

OUTLET: Where to ....

Description:

	Size and Shape	*Material*	*Location*	*Elevation*
1.				
2.				

Gaging possibilities ....

Conditions below outlet: Color ....

Turbidity .... Deposits ....

SANITARY SEWAGE: Disposal .... Persons tributary ....

REMARKS ....

Survey by .... Date ....

G-1 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Office Record—Municipal reports

River Basin ______________________

City and State	County	Subwatershed	Survey amde	Report Cincinnati	Forward S. H. D.

G-2 Field Report—Transmittal Form

FEDERAL SECURITY AGENCY

U. S. PUBLIC HEALTH SERVICE

State ____________________
Report Letter No. __________
Date _______________ 19____

ENGINEER OFFICER IN CHARGE,
U. S. Public Health Service, Ohio River Pollution Survey,
East Third and Kilgour Sts., Cincinnati, 2, Ohio.

SIR: Attached are original reports covering factual field data on the following cities and/or industries, as indicated:

Respectfully,

____
Public Health Engineer
Assigned Field Duty.

G-3 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Population in Incorporated Places

State __________________ County __________________

Town Name	Basin Number	Population				
		1940	1930	1920	1910	

G–4 Sheet---- of----

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Population in Unincorporated Places

River Basin-------------------- State--------------------

County	Population in Unincorporated Places in County				% of County in Basin	Population in Unincorporated Places in Basin			
	1940	1930	1920	1910		1940	1930	1920	1910
Total									

G–5 Sheet---- of----

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Population Summary

River Basin-------------------- State--------------------

Size of Town	1940		1930		1920		1910	
	No.	Pop.	No.	Pop.	No.	Pop.	No.	Pop.
Less than 250								
250–499								
500–999								
1,000–2,499								
Subtotal								
2,500–4,999								
5,000–9,999								
10,000–24,999								
25,000–49,999								
50,000–99,999								
100,000 or over								
Subtotal								
Population in Incorporated Places								
Population in Unincorporated Places								
Total Population								

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OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Industries—Preliminary List

River Basin-------------------- State--------------------

Name of Plant	City	County	Industry	Product	No. Employees

G-7 Sheet---- of ----

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO

Water Supplies

River Basin-------------------- State--------------------

Location	State	Mileage Index Number	Population		Cons. M. G. D.	Source	Treatment	Owner	Remarks
			Total 1940	Served					

G–8 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO Sheet---- of----

Industrial Wastes—Watershed Summary

River Basin-------------------- State--------------------

Mileage Index No.	Name of plant	Municipality	County	Type of industry	Plant employees	Operating months	Waste—1,000 g. p. d.		Remedial measures	City sewer	Receiving stream	Sewered Pop. equivalent		Flow diagram	Date visit	Remarks
							Cooling	Other				B. O. D.	Susp. Sol.			

G–9 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO Sheet --- of----

Sources of Pollution—Watershed Summary

River Basin-------------------- State--------------------

Location	State	Mileage Index Number	Total 1940 Pop.	Sewerage				Population Equivalent (B. O. D.)				
				Pop. Connected	Type	Flow	Treatment	Sewage		Ind. Waste	Total	
								Untrt.	Disch.		Untrt.	Disch.

G–10 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO Sheet____ of____

Costs for Municipal Waste Treatment

River Basin____________________ State____________________

City	1940 Pop.	Fut. Pop.	Ind. Flow m. g. d.	Design Pop.	Installation costs				Operating costs		Remarks
					Interceptor		Treatment Plt.		Primary	Second.	
					Per cap.	Total	Primary	Second.			

G-11 OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO Sheet____ of____

Costs for Industrial Waste Treatment

River Basin____________________ State____________________

Location & Name of Plant	Type of Industry	Type Treatment Proposed	Cost of Correction						
			Installation Cost				Annual Charges		
			Connection	Ind. Treat.	Pre-treat.	Total	Int. & Amor.	Oper.	Total

APPENDIX VI

PERSONNEL

Information on sources of pollution was collected under the administrative direction of Sanitary Engineer Director H. R. Crohurst,[1] in charge of the Office of Stream Sanitation at Cincinnati, Ohio. The work was organized and carried out under the technical direction of Sanitary Engineer (R) Ellis S. Tisdale, with the assistance of Senior Public Health Engineer M. LeBosquet, Jr., in charge of industrial waste activities, and Passed Assistant Sanitary Engineer Mark D. Hollis, in charge of municipal water supply and sewerage activities. Assisting Mr. LeBosquet was Associate Public Health Engineer Samuel R. Weibel, and assisting Mr. Hollis was Associate Public Health Engineer Richard L. Woodward. Messrs. Weibel and Woodward also handled special assignments.

During 1940, Assistant Sanitary Engineer (R) Paul D. Haney and Assistant Sanitary Engineer (R) Paul E. Seufer were added to the staff and placed on special assignments. Assistant Sanitary Engineer (R) Ralph C. Palange and Assistant Public Health Engineer William T. Eiffert were added to the Cincinnati office. Certain field engineers, transferred to Cincinnati after completion of field assignments, assisted in the early phases of preparation of the final report.

Due to the need for experienced personnel in connection with emergency health and sanitation activities, Mr. Tisdale was transferred in March 1941, and Mr. Hollis in April 1941, to other duties, and the final phases of the work were supervised by Mr. LeBosquet under Mr. Crohurst's direction.

Field engineers assigned to state health departments and the Tennessee Valley Authority for the actual collection of information during 1939 were as follows:[2]

Ohio:
- Gordon E. McCallum, associate public health engineer.
- Charles D. Yaffe, assistant public health engineer.

West Virginia:
- Charles R. Keatley, associate public health engineer.
- H. Gardner Bourne, Jr., assistant chemical engineer.

Kentucky:
- Archie B. Freeman, assistant public health engineer.
- George D. Reed, assistant public health engineer.

Tennessee:
- Arvo A. Solander, assistant public health engineer.

Tennessee Valley Authority:
- Richard F. Poston, associate public health engineer.

[1] Deceased.
[2] Official designations apply to the last day of each person's connection with the Ohio River pollution survey.

During the expanded program of 1940, the 1939 field staff served as a nucleus and the field organization was as follows:

Pennsylvania-New York:
- Mr. Keatley in charge.
- Sterling M. Clark, assistant sanitary engineer (R).
- Joseph E. Flanagan, Jr., assistant sanitary engineer (R).
- Edward N. McKinstry, assistant public health engineer.
- William C. Murray, assistant public health engineer.
- Emanuel H. Pearl, assistant public health engineer.
- Ray Raneri, assistant sanitary engineer (R).

(Following Mr. Keatley's transfer to other duties, Mr. Pearl, and later Mr. Flanagan, were placed in charge at this office.)

Ohio:
- Mr. Yaffe in charge.
- James G. Terrill, Jr., assistant sanitary engineer (R).

West Virginia:
- Mr. Bourne in charge.
- Daniel A. Okun, assistant sanitary engineer (R).

Kentucky:
- Mr. Freeman and Mr. Reed.

Indiana-Illinois:
- Mr. McCallum in charge.
- Ralph J. Johnson, assistant sanitary engineer (R).
- Edwin B. Joseph, assistant sanitary engineer (R).
- Royal E. Rostenbach, assistant chemical engineer.
- Charles C. Spencer, assistant sanitary engineer (R).

(Following Mr. McCallum's transfer to other duties, Mr. Spencer was placed in charge of this office.)

Tennessee:
- Mr. Solander.

Tennessee Valley Authority:
- Mr. Poston in charge.
- Ralph Porges, assistant sanitary engineer (R).

Special assignments consisted of—

1. Municipal Treatment Plant and Intercepting Sewer Costs, by Mr. Hollis.
2. Population Studies, by Mr. Woodward.
3. Preparation of Industrial Waste Guides (see Supplement D) under the supervision of Mr. LeBosquet: by Mr. Weibel (6 guides), Mr. LeBosquet (3 guides), Mr. McCallum (2 guides), Mr. Reed (2 guides), Mr. Bourne (1 guide), and Mr. Porges (1 guide). Mr. Woodward and Mr. Palange assisted in revising the guides for the final report.
4. Industrial Waste Treatment Costs, by Mr. Weibel.
5. Acid Mine Drainage Studies (see Supplement C) by Messrs. LeBosquet and Haney, assisted by Messrs. Palange and Rostenbach.
6. Administration of Pollution Abatement, by Mr. Seufer.

SUPPLEMENT B

ORGANIZATION AND METHODS OF LABRATORY STUDIES

ARMY MEDICAL LI
WASHINGTON, D. C. U. S. A.

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ORGANIZATION AND METHODS OF LABORATORY STUDIES

Introduction

The laboratory studies carried out in connection with the Ohio River Pollution Survey have constituted one of the three major parts of the survey, the other two being concerned, respectively, with the collection of data on sources of pollution and with the measurement of the volume of flow of the streams in the Ohio River Basin during the period of the survey. From the standpoint of operations, the laboratory studies have been in some respects the most difficult and complex activity connected with the survey, as they have involved the systematic examination of practically every stream in the 204,000 square miles of territory included within the basin, except in certain limited areas of the Scioto,[1] Tennessee, Cumberland, and Miami watersheds, where recent laboratory observations had been carried out by other agencies.

The methods and results of the routine laboratory operations of the survey have been described somewhat briefly in connection with the main report of the survey, including a presentation of the results of the stream examinations in complete tabular form. Owing to the limited space available in the main report, however, it has not been practicable to give in that report certain details concerning the planning and methods of carrying out the laboratory operations of which a record would be desirable elsewhere for the benefit of those undertaking similar work in the future.

Objectives of Laboratory Studies

The main objectives of the laboratory studies have been as follows:

1. To ascertain, by means of systematic laboratory tests, the sanitary quality of the waters of the main Ohio River and its tributary streams at various points throughout the entire drainage basin and especially above and below recognized sources of pollution.

2. To examine streams in the mining sections of the basin for evidences of acid mine wastes and their effects.

3. To study, so far as practicable, certain special problems resulting from stream pollution along the Ohio River and its tributary streams, notably—

   (*a*) The measurable effects of mine sealing on the acidity of streams receiving mine wastes.

   (*b*) The presence in stream waters of substances causing tastes and odors in water supplies, notably phenolic substances causing chlorophenol tastes, which have been most commonly prevalent in water supplies of the Ohio Basin.

   (*c*) The presence of sludge deposits in pooled sections of the main Ohio River.

[1] See Public Health Bull. 276, U. S. Public Health Service.

4. To observe, by methods of biological study, the effects of sewage and industrial wastes pollution on the plankton and higher aquatic life, notably fish life, in various typical streams throughout the Ohio Basin.

In undertaking a systematic examination of stream waters throughout the Ohio River Basin, it was essential to have in mind the divergent effects which variations in the flow and temperature of a stream may have on the sanitary quality of its water at different times. From the standpoint of general sanitary conditions, the more critical flows and temperatures usually occur during the dry-weather conditions of summer, when the volumes of diluting water carried by streams are at their minimum and increased water temperatures tend to promote the more rapid biochemical decomposition of organic polluting materials at a time when the normal dissolved oxygen content of a stream is at its lowest level. From certain other standpoints and notably with respect to the use of streams for water supplies, more critical conditions may occur during periods of increased stream flows, especially following prolonged low-water conditions.

Although every effort was made to observe stream conditions over as much of the basin as practicable during "critical" flow periods such, as above indicated, it was not feasible to carry out such observations simultaneously except over restricted areas, because each laboratory unit was limited in its coverage to a radius of about 50 miles from a particular location point. Moreover, the long periods of drought which occurred throughout the years 1939 and 1940, though facilitating the extension of laboratory observations to more areas during low-water periods than otherwise would have been possible, reduced correspondingly the opportunities for high-water observations during periods of the winter and spring when these conditions normally would be expected to prevail. One advantageous circumstance which resulted from the abnormal prolongation of drought conditions through the winters of 1939 and 1940 was the opportunity thus provided for observing some streams under low-water conditions both in summer and in winter, with stream temperature the only important variable to be considered as affecting the sanitary quality of the streams during these two different seasons.

The effects of mine wastes on streams in large sections of the Ohio River Basin devoted to soft-coal mining are known in general terms, but had not been measured systematically by means of stream observations to any considerable extent prior to the present survey. Owing to the extensive program of mine sealing which has been in progress in different parts of the basin, it was considered especially important to carry out analyses of stream waters in the areas both affected and unaffected by sealing operations. As these tests were made in connection with other laboratory operations, their results have had a definite significance, both in themselves and in relation to those of routine examinations bearing on general sanitary conditions in the same streams.

The special studies above enumerated have been carried out for different reasons. The study of changes in stream acidity resulting from mine sealing were instituted in order to ascertain more definitely than could be determined by ordinary observational methods the effects of mine sealing in quantitative terms of stream impovement. This study, instituted late in 1940, was confined to a test area near

Morgantown, W. Va., where the effects of complete and partial mine sealing, with an unsealed area as a control, could be observed over a period of several months with all other conditions, geological and meteorological, practically the same for each subdivision of the test area.

The study of substances causing tastes and odors in water supplies was undertaken in cooperation with the departments of health of Ohio, Pennsylvania, and West Virginia, as presenting one of the more serious problems of industrial wastes pollution affecting water supplies in the upper section of the Ohio Basin. This study was centered in the lower Kanawha River and in the Mahoning-Beaver area.

The study of mud deposits was one of special interest as bearing on the extent and distribution of these deposits in pooled sections of the river and on the degree to which they are affected by organic solids originating in sewage and industrial wastes. The deoxygenating effect of sewage deposits, where prevalent in relatively large quantities, would tend to impose an added burden on the oxygen resources of the overlying stream.

The biological study of the effects of stream pollution on plankton and higher aquatic life was an essential part of the regular laboratory survey, as it dealt with an important phase of the problem untouched by the other laboratory observations. Probably the most important practical element in the biological phase of this problem has been the effects of pollution on fish life. This question, though studied by the United States Bureau of Fisheries in connection with its other investigations, had not been considered previously with specific reference to the pollution of the Ohio River and its tributary streams. It had not been touched upon in any previous sanitary surveys of the Ohio River. Its importance in relation to the recreational use of streams in the Ohio Basin, as well as to the maintenance of desirable sanitary conditions in streams devoted to other uses, afforded ample justification for a thorough study of it in connection with this survey. As this study has been covered fully in a separate report by the biologist of the survey, it will not be dealt with in the present supplement.

Organization of Laboratory Operations

In accordance with a general plan of operations adopted in October 1938, the Stream Pollution Investigations Station of the Public Health Service at Cincinnati was designated to undertake the necessary laboratory work incidental to the Ohio River pollution survey. The instructions issued in this connection included authorization for detailing necessary personnel to the work from the regular staff of the station, for nominating additional personnel, and for obtaining all supplies and equipment necessary to carrying out the laboratory operations. An officer of the Cincinnati station was detailed to organize and direct the laboratory work, and other officers have acted as technical advisers from time to time.

The original plan of the survey, as approved by the supervisory Ohio River Committee, provided for a 3-year period of laboratory observations, covering approximately one-third of the entire basin each year and using the same personnel and equipment from year to year. The section to be covered during the first year, 1939, included the entire

area draining into the Ohio River from the Kanawha to the Kentucky River, inclusive.

In order to carry out the laboratory operations, a staff of 30 technicians, office workers, and field assistants was assembled early in 1939, trained at the Cincinnati station, and assigned to duties as rapidly as thorough training permitted. Meanwhile, equipment was purchased for a fixed base laboratory at the Cincinnati station, which was made the headquarters for the work, and a floating base laboratory was equipped on the quarter boat *Kiski*, loaned for the purpose by the Corps of Engineers, United States Army. Active laboratory work was started at the Cincinnati laboratory in February 1939, while the assembly of personnel and equipment was in progress. Two mobile trailer laboratories were purchased and equipped for observations in the more distant areas of the drainage basin, not readily accessible from the base laboratories located on the main Ohio River. Two motorboats, loaned by the United States Bureau of Fisheries, were overhauled and outfitted for sample collection work on the main river.

After the first year of operations had been carried out according to the original plan, the Ohio River Committee met in February 1940, and decided to have the entire survey completed during the year 1940, so far as practicable, thus compressing into 1 year the work originally planned for 2 years. This decision involved practically a twofold intensification of laboratory operations, with added equipment and augmented personnel. The latter consisted of 27 more workers added to the original staff, making a total personnel numbering 57. Additional equipment purchased in order to carry out this intensified plan included 4 more mobile laboratories and 2 new motorboats, together with a considerable amount of laboratory apparatus and supplies.

In the accompanying map (fig. 1) is shown a double-hatched area marking the territory covered by laboratory operations in 1939, aggregating some 60,000 square miles. The unhatched portion, totaling about 144,000 square miles, was the area covered by operations in 1940, including portions of the Tennessee and Cumberland Basins surveyed by the Tennessee Valley Authority and the Tennessee Department of Health respectively. This portion of the map also shows by arrows the general routes of mobile laboratory operations and the section covered by the *Kiski* laboratory.

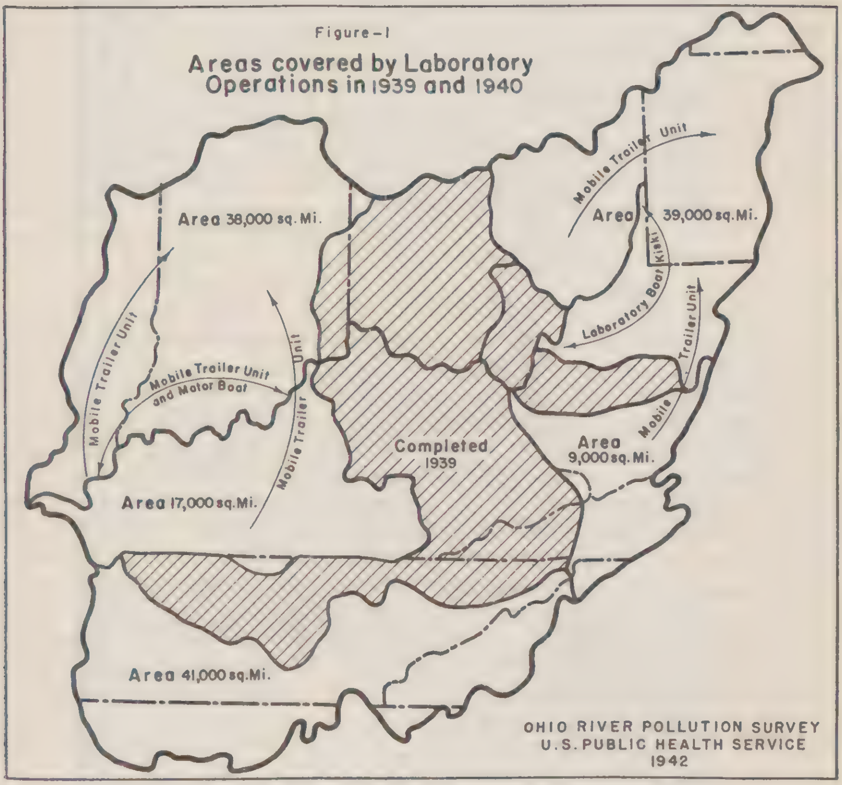


Figure-1
Areas covered by Laboratory Operations in 1939 and 1940

TABLE 1.—*Schedule of routine laboratory operations, by months, 1939–41*

Watershed	1939												1940												1941			
	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April
Allegheny	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	T	T	----	----	----	----
Monongahela	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	T	T	T	T	----	----	----	----
Beaver	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	----	K	K	K	T	----	----	----
Muskingum	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	KT	KT	KT	K	K	----	----	----	K	K	K	----
Little Kanawha	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	K	K	K	K	K	----	----	----	K	K	K	----
Hocking	----	----	----	----	----	----	----	----	----	T	T	----	----	----	----	T	T	K	K	K	K	----	----	----	K	----	----	----
Kanawha	----	----	----	----	----	----	----	K	K	K	K	KT	KT	KT	KT	KT	T	T	----	----	----	----	----	----	----	T	----	----
Guyandot	----	----	----	----	----	K	K	K	K	KT	KT	K	K	K	KT	KT	----	----	----	----	----	----	----	----	----	----	----	----
Big Sandy	----	----	----	----	----	K	K	K	K	K	KT	KT	K	K	K	K	----	----	----	----	----	----	----	----	----	----	----	----
Scioto	S	S	S	S	S	S	SC	C	TC	TC	TC	C	C	C	C	C	----	----	----	----	----	----	----	----	----	----	----	----
Little Miami	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	----	----	----	----	----	----	----	----	----	----	----
Licking	----	C	C	C	C	C	C	C	CT	CT	CT	CT	C	C	C	----	----	----	----	----	----	----	----	----	----	----	----	----
Miami	----	C	C	C	C	CD	CD	CDT	CDT	CD	CD	CD	C	C	C	C	----	----	----	----	----	----	----	----	----	----	----	----
Kentucky	----	----	C	C	C	C	C	C	CT	CT	CT	C	----	C	C	C	----	----	T	----	----	T	----	----	T	----	----	----
Salt	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	----	T	----	----	----	T	----	----
Green	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	----	----	T	----	----
Wabash	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	T	----	----	T	----	----
Cumberland	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	----	T	T	T	----
Tennessee	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	----	T	T	T	----
Ohio—Pittsburgh, dam 13	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	----	T	K	K	K	K	----	T	----
Ohio—dam 14 to dam 22, inclusive	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	K	K	K	K	K	----	----	----	K	K	K	----
Ohio—Point Pleasant, dam 32	----	----	----	----	----	K	K	K	K	K	K	K	K	K	K	KT	----	----	----	----	----	----	----	----	----	----	----	----
Ohio—dam 33 to dam 38, inclusive	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	----	----	----	----	----	----	----	----	----	----	----
Ohio—below dam 39 to mouth	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	T	T	T	T	T	T	T	T	T	----

Symbols: C = Cincinnati laboratory; K = *Kiski*; T = Trailer laboratory unit; S = Scioto River investigation; D = Dayton sewage laboratory.

In table 1 is shown a time schedule, by months, of the routine laboratory operations carried out during the entire period of the survey. The operations during the year 1939, in the middle-third area of the basin were shared by five different types of laboratory units, including those of the Scioto River investigation, a separate project of the Public Health Service, and the Dayton sewage treatment plant, which cooperated with the survey in laboratory observations in the lower section of the Miami River. During this period, continuing observations by the Cincinnati and *Kiski* laboratories covered parts of eight tributary areas, in addition to the middle-third section of the main Ohio River from Point Pleasant to dam 39. During the year 1940 and up to the end of March 1941, the laboratory operations were carried out by the *Kiski* laboratory, along the upper section of the Ohio River, and by the six mobile trailer laboratories, in the outlying tributary areas and along the lower section of the main river. Operations in the upper and lower tributary areas in 1940 were not continuous during periods of several months, as was the case in 1939 for the middle-third area. This was due to the necessity of covering more areas by means of mobile laboratory units, which in some instances were obliged to work back and forth from one tributary area to another, in order to economize on time and travel distances.

Methods of Laboratory Operations

During the year 1939, laboratory operations along the middle third of the Ohio River were divided between the base laboratory at Cincinnati and the floating *Kiski* laboratory located at dam 29, just above Ashland, Ky. During the year 1940, the upper section of the main Ohio River was covered from the *Kiski* laboratory at two locations, East Liverpool and Marietta, respectively. The lower section, extending from the Kentucky River to the mouth of the Ohio at Cairo, was covered by a mobile trailer laboratory with a motorboat for sample collecting in the main river. The other five trailer laboratories covered the entire outlying tributary areas except those within convenient access to the base laboratories located along the main river. Portions of the Cumberland and Tennessee River Basins were omitted from the survey because they were being or recently had been covered by the Tennessee Health Department and the Tennessee Valley Authority, respectively.

SAMPLE COLLECTIONS

Through the cooperation of the Corps of Engineers, arrangements were made for the regular collection of samples at the locks and dams along the upper and middle section of the main Ohio River. These collections were made by the lock personnel, using boats with outboard motors, in accordance with a schedule providing for two or three collections each week at each lock.[2] Samples were collected at three points on a cross section located 1,000 to 1,500 feet upstream from the dam. Deep water sampling equipment was used, similar to that previously developed by the Public Health Service in other stream surveys. All samples were collected at mid-depth points in

[2] For detailed instructions on the collection of these samples, see appendix 1, memorandum No. 1.

the stream cross section. After being collected, the samples were transported by automobile without delay to the nearest base laboratory for analysis.

For the collection of samples from tributary points located within convenient travel distance from the base laboratories, regular personnel were employed by the survey. These sample collectors used their own automobiles for transportation and either highway bridges or boats as means of reaching the stream sampling points. On the tributary streams samples were collected generally at midpoints and middepths, using a deep or shallow water sampler, as needed. For reaching some points at the mouths of main tributaries and in the Ohio River between the locks and dams, motorboats were used, being operated by survey personnel.

In figures 2 to 7, inclusive, are shown illustrative views of the equipment used in collecting samples of the stream waters and bottom mud deposits.[3] Figure 2 gives two views of the deep-water sampler, assembled and unassembled. The sampler is made of heavy cast bronze, with a rubber gasket sealed cover and weighted with lead in the bottom. In figure 3 is a view of the sampler mounted on a bridge hoist, ready for action. Figure 4 pictures a surface or shallow stream sampler, mounted on a pole. In figure 5 is shown a deep-water mud deposit dredge of the clam-shell type, mounted on a hoist and operated by a hand winch. This dredge can be operated in stiff materials such as clay, and will bring up about one-half cubic foot or more of mud. Figure 6 shows two views of a light weight surface mud sampler, one being in an open position as lowered to the deposit and the other in a closed position after collection of the mud sample. Both this and the clam-shell dredge were devised by Public Health Engineer C. T. Carnahan of the Public Health Service. In figure 7 is pictured one of the motorboats at the time of collecting a sample of river water. This was one of the two older boats loaned by the United States Bureau of Fisheries.

In figure 8 is an illustration of the floating laboratory *Kiski* loaned by the Corps of Engineers, the lower deck being used for laboratory work and the upper deck as an office and living quarters for the crew and unmarried men of the technical staff. The members of the staff quartered on the boat provided and maintained their own sleeping quarters and commissary. Every man in the staff was called upon to help with the mooring and navigation of the boat, as required, though three shipkeepers were employed expecially for this purpose. A 24-hour watch was maintained by these men as a part of their regular duties. The engineer in charge of the laboratory also was responsible for the maintenance and navigation of the boat and its equipment.

TRAILER LABORATORIES

The general method of operating the mobile laboratories was as follows: Before undertaking the survey of a given area, maps were prepared at the Cincinnati headquarters showing the sampling point locations for different stream areas and a central place in each area at which the mobile laboratory could be located for a period of 2 or

[3] For a detailed description of this equipment, see article on Mechanical Aids for Stream Surveys by C. T. Carnahan, Public Health Reports, vol. 56, No. 16, April 18, 1941, pp. 815–821.

FIGURE 2.—Deep water sampler, open and closed

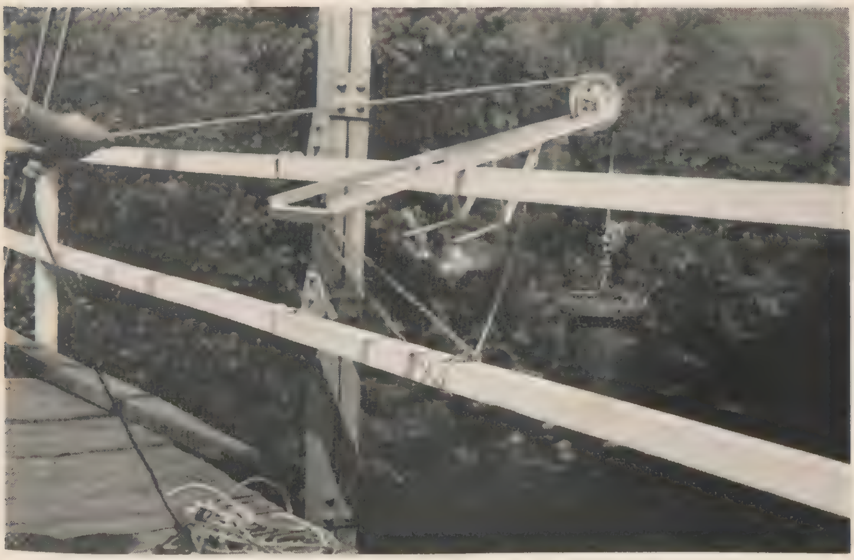


FIGURE 3.—Sampler hoist, mounted on a bridge.

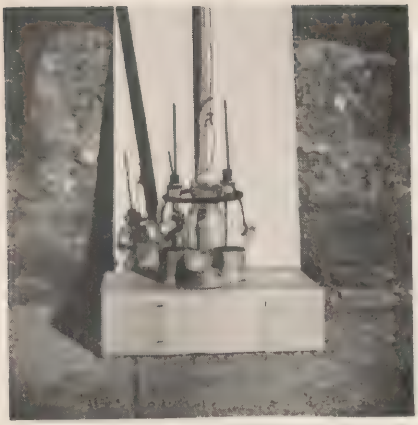


FIGURE 4.—Shallow water sampler.

FIGURE 5.—Clam-shell mud dredge sampler.

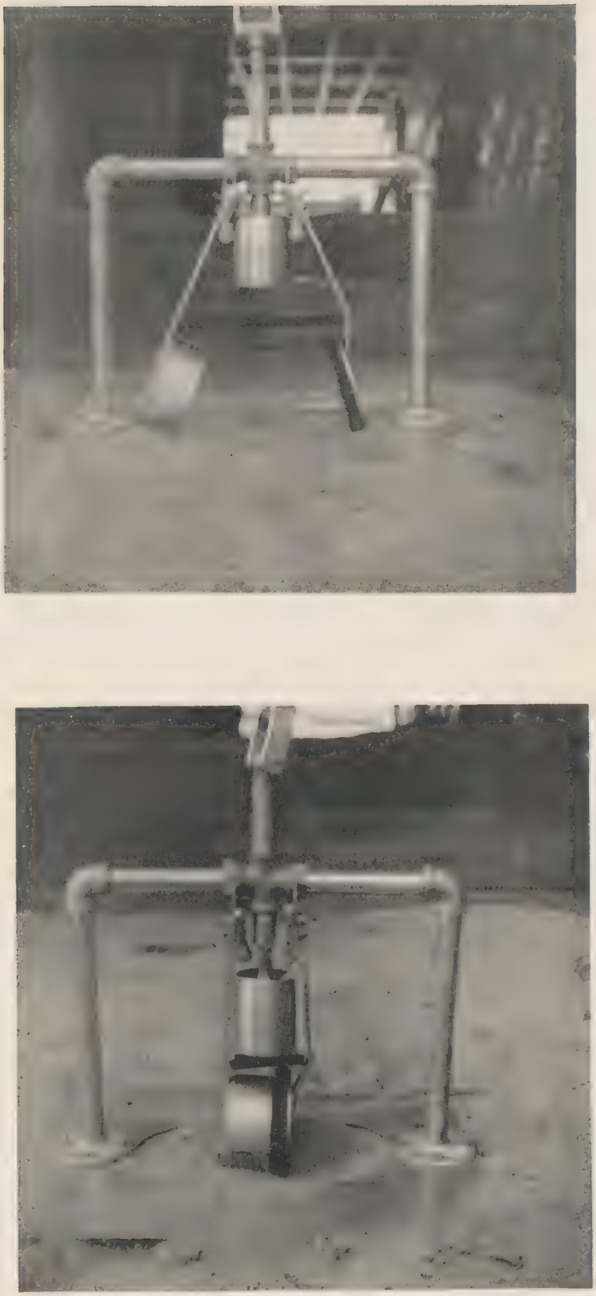


FIGURE 6. -Surface mud sampler, open and closed.

FIGURE 7.—Collecting a river water sampler from a motorboat

FIGURE 8.

3 weeks while the particular area was being covered by stream examinations. Preliminary correspondence resulted in a tentative location for each stopping place of the mobile units. The travel routes for each unit were laid out for successive areas to be covered and an estimate made of the necessary time schedule of travel. As previously noted, a field engineer was sent in advance to complete detailed arrangements for each location and to survey the tentative sampling points, relocating them where local conditions indicated this to be desirable. The field engineer then prepared a detailed map showing the exact location of each sampling point and the highway routes necessary to reach it from the central location. This information, together with any other pertinent data, was turned over to the chemist in charge of each mobile unit, which then proceeded with its work in each location with a minimum loss of time. In figure 9 is a typical guide map showing the location of a sampling point.

Each mobile laboratory was manned by a crew of three men, consisting of a chemist in charge, a laboratory attendant, and a chauffeur-sample collector. In the accompanying map (fig. 10) are shown the travel routes and central location points followed by each mobile unit during the campaigns of 1939 and 1940. In figures 11 to 13, inclusive, are typical exterior and interior views of a trailer laboratory. An interior floor plan is shown in figure 14.[4]

In practice, the mobile laboratories usually were located at local waterworks or sewage treatment plants, where continuous supplies of water and electric current were available. These supplies were connected directly to the laboratory through extension hose and cable, forming part of the trailer equipment. Supplies of chemicals and apparatus were maintained by shipments from the headquarters laboratory at Cincinnati.

Laboratory Determinations and Methods

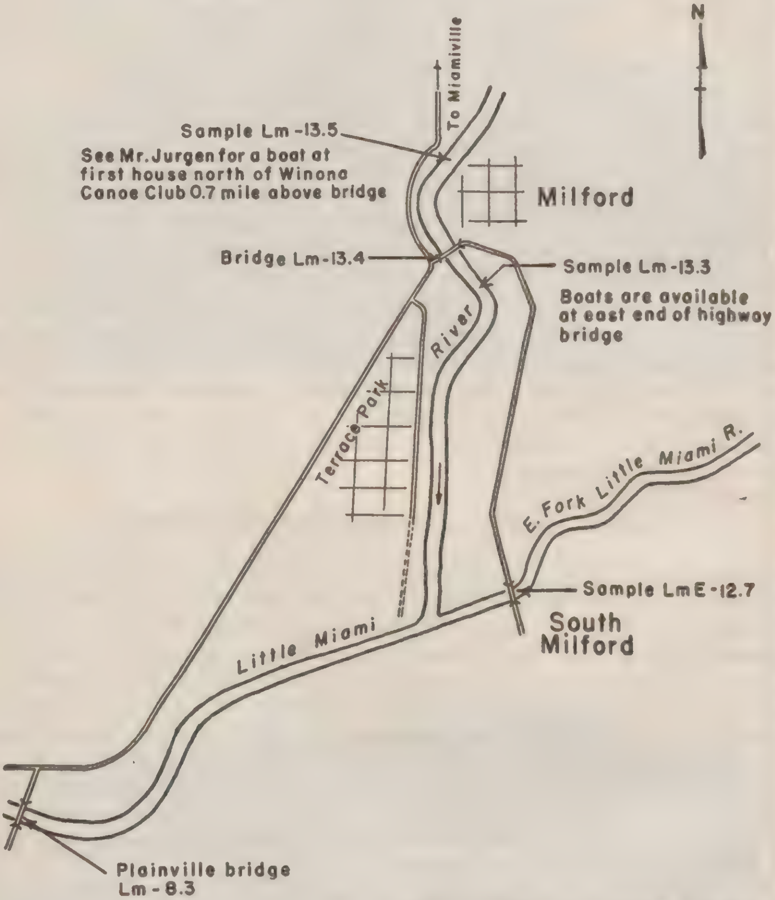
Every possible effort was made in the laboratory work of the survey to obtain comparable results in accordance with current standard methods of water examinations. Recognizing that with several laboratories in operation, small variations in procedure might tend to vitiate the mutual comparability of the results, a systematic and thorough instruction in laboratory methods was given to each technician at the Cincinnati headquarters laboratory before his assignment to regular duty. This course of instruction usually occupied from 4 to 6 weeks. Throughout the progress of the field work, a qualified member of the laboratory staff was detailed to visit in turn each base and mobile laboratory in order to check analytical methods and results and to correct any inconsistencies.

In this connection, detailed instructions also were given to the chemists in charge of mobile laboratory units concerning the management of these units. In this connection reference is made to appendix I, memorandum No. 11, which contains information prepared especially for the mobile laboratory crews. In memorandum No. 2 of the same appendix is a general statement of the plan and objectives

[4] For a detailed description of the trailer laboratories, see article on Mobile Laboratory Units of the Ohio River Pollution Survey, by F. E. DeMartini, Public Health Reports, vol. 56, No. 15, Apr. 11, 1941, pp. 754–760; see reprint No. 2259. Detailed specifications for these units are given in appendix II of this supplement.

Figure-9

Typical Map of Sampling Point Locations



OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

Fig.-10

OHIO RIVER BASIN

LOCATION OF LABORATORY
UNITS DURING PROGRESS OF THE
OHIO RIVER POLLUTION SURVEY 1939-1941

OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION

Fig.-10

FIGURE 11.—Trailer laboratory with towing car

FIGURE 12.—Trailer laboratory in operation.

FIGURE 13.—Trailer laboratory, inside view.

Fig.-14

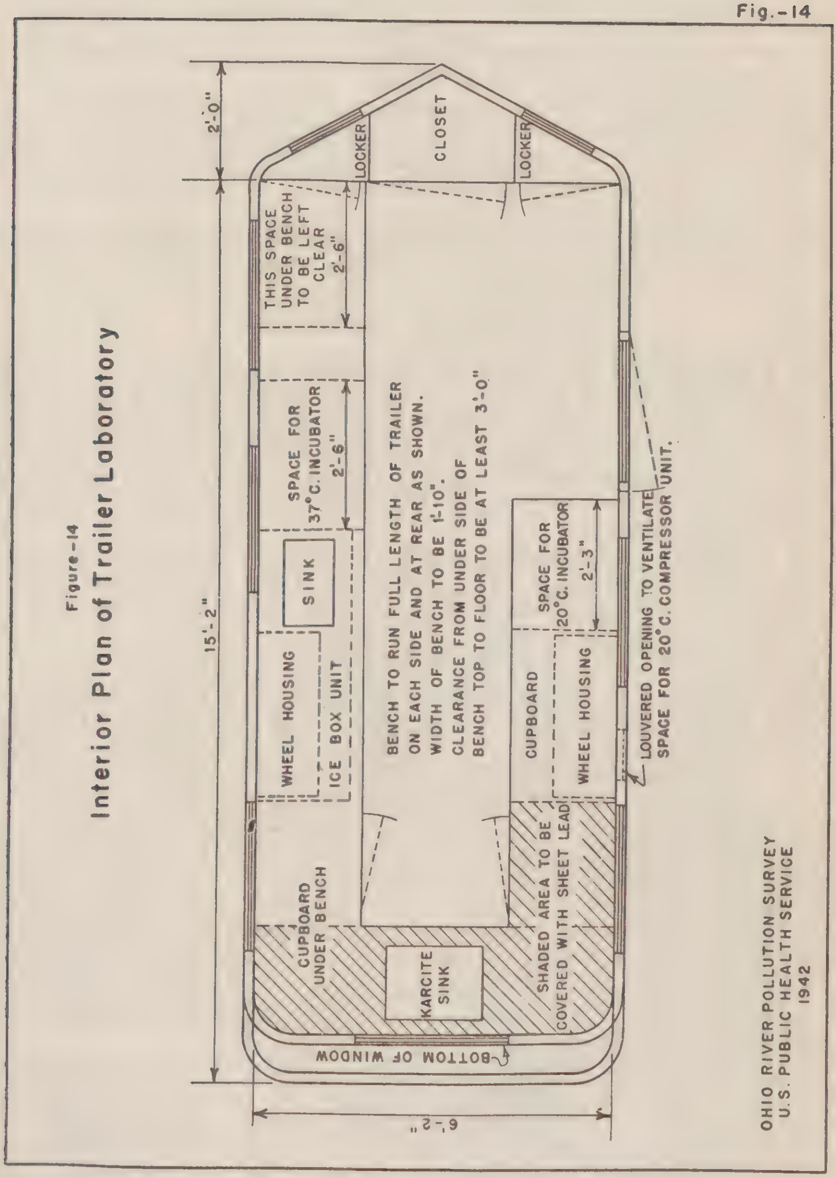


Figure-14
Interior Plan of Trailer Laboratory

of the survey which was prepared for the guidance of all of the members of the laboratory staff.

The routine laboratory tests made on stream water samples were as follows:

(*a*) Physical and chemical tests (see appendix I, memorandum No. 4): (1) Temperature; (2) turbidity; (3) pH value; (4) alkalinity; (5) total and volatile suspended matter[5]; (6) dissolved oxygen; and (7) 5-day biochemical oxygen demand at 20° C.

(*b*) Bacteriological tests (see appendix I, memorandum No. 3): (1) 24-hour agar plate count at 37° C.;[5] (2) coliform bacteria, most probable numbers, by standard fermentation tube test at 37° C.; (3) direct plate count of coliform bacteria on brilliant green lactose bile medium at 37° C.[5]

The following brief notes may be inserted at this point to explain the significance of the various tests above enumerated.

A. PHYSICAL AND CHEMICAL TESTS

(1) *Temperature.*—The temperature of stream waters governs their solubility for oxygen and hence the saturation level of dissolved oxygen in streams. This saturation level varies inversely with the stream temperature, being lower at higher temperatures and vice versa. Temperature also has a marked influence on rates of natural purification, which are increased at higher temperatures and diminished at lower temperatures.

(2) *Turbidity.*—In stream waters, turbidity is measured in terms of parts per million (p. p. m.) or milligrams per liter, of a standard suspension of diatomaceous earth. It is an index of the density of silt, or other suspended matter, carried by a stream.

(3) *pH value.*—The symbol "pH" denotes the logarithm of the reciprocal of the hydrogen ion concentration in a given water, this symbol being a universal one in chemistry. In general, the pH value indicates the relative acidity or alkalinity of a water, being lower with higher degrees of acidity. The normal value for neutral distilled water is 7.2, higher values indicating the presence of alkaline earth salts, and lower values the presence of acids or acid salts.

(4) *Alkalinity.*—The alkalinity of a natural water represents its content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is measured by titration with a standard solution of a strong acid to certain standard datum points or hydrogen ion concentrations. In the present survey, standard sulfuric acid has been used, with methyl orange as an indicator, showing a definite color change at a hydrogen ion concentration of 0.0001 (or pH 4.0).

(5) *Total and volatile suspended matter.*—The total suspended matter content of a natural water is determined by filtering a sample of standard volume and weighing the dried residue. It represents the concentration of suspended matter in terms of dry solids. The volatile matter is determined by the loss of weight in the total dry solids after the application of heat under standard time and temperature conditions. It is a measure of the suspended organic matters present in the water.

[5] Discontinued as a routine test after the end of the year 1939.

(6) *Dissolved oxygen.*—Although oxygen is only slightly soluble in water (about 9.2 parts per million at 20° C.), it can be measured accurately to less than 0.1 part per million. Dissolved oxygen is essential to the natural purification of stream waters and to the maintenance of fish and other aquatic life. In natural bodies of water, the dissolved oxygen is drawn upon to support biochemical oxidation of organic waste matters, but tends to be replenished by absorption from the atmosphere and the photosynthetic action of some water plants, including algae. A deficiency in the dissolved oxygen content of a polluted stream below the saturation level indicates the presence of polluting organic substances which are absorbing oxygen from the stream water. The degree of this deficiency is a measure of the deoxygenating effect of polluting matters and hence an index of the degree of pollution in a particular stream zone.

In an ideal situation in which a stream receives sewage or industrial waste at a single point and rapid admixture with the stream water takes place, the dissolved oxygen content tends to follow a typical sag curve on the basis of time and temperature, reaching a minimum point usually in 1 to 3 days' time of flow below the source of pollution, depending on the temperature, oxygen demand, and rate of reaeration. The specific rate of atmospheric reaeration is influenced slightly by stream temperature, but largely by the turbulence of flow, which varies widely in different streams, or sections of the same stream. The minimum point of the oxygen sag curve is perhaps its most important parameter from an observational standpoint, as it marks the most unfavorable condition which may affect fish and other aquatic life, or the possibility of occurrence of nuisance conditions in a stream. Desirable limiting requirements in this oxygen minimum point are discussed in the main report of the survey.[6]

(7) *Five-day biochemical oxygen demand.*—The standard test for biochemical oxygen demand (B. O. D.) involves the incubation of sealed samples of a stream water for 5 days at 20° C., and the measurement of the loss of dissolved oxygen by the sample during the period of incubation. This loss represents the 5-day biochemical oxygen demand of the sample. When diluted initially with B. O. D.-free water, the oxygen demand of the original sample is found by applying the dilution ratio to the measured loss of dissolved oxygen.

The biochemical oxygen demand as thus determined is a measure of the amount of dissolved oxygen which may be expected to be absorbed from a stream water in 5 days at 20° C. in order to support the biochemical oxidation of the organic pollutants carried in the stream at the time of observation. Organic matters originating in sewage have been found experimentally to be oxidized in this manner according to a logarithmic time-function curve, which varies in its rate of progression with the water temperature, the rate being faster at higher temperatures. Hence it is possible to estimate the amount of oxygen demand satisfied in any time and at any temperature, having observed it at a standard time and temperature.

[6] See pp. 32-35, introductory and general sections, Report to Ohio River Committee.

B. BACTERIOLOGICAL TESTS

(1) *Twenty-four-hour plate count at 37° C.*—This determination consists in mixing a measured portion of the water sample with a melted sterile culture medium containing agar, spreading the mixture in a sterile glass Petri dish, allowing it to become hardened to a stiff, jelly-like consistency and incubating the hardened culture for 24 hours at 37° C. At the end of this period, visible colonies formed from individual or clumped bacterial cells are counted and their number is taken as an index of the density of bacteria in the original sample. As the species of water bacteria appearing on these plate cultures are numerous and varied, the bacterial count obtained in this manner is only roughly indicative of pollution. When considered in conjunction with the determination of numbers of coliform bacteria, the plate count is of value, both as an indicator of pollution and as a rough measure of natural purification.

(2) *Determination of coliform bacteria.*—This determination affords the most delicate and specific test for pollution of stream waters by sewage, as it shows the approximate density of a group of bacteria which are always present in large numbers in sewage and are relatively few in numbers in other stream pollutants. Coliform bacteria are normal inhabitants of the intestines of warm-blooded animals and are discharged in very large numbers in human feces, which constitute the principal source of these bacteria in sewage.

The test for coliform bacteria is made by adding measured portions of a water sample to a lactose broth liquid culture medium in tubes especially designed for showing gaseous fermentation of the lactose. After 24 to 48 hours of incubation at 37° C., tubes showing the presence of gas are considered as giving presumptive evidence of the presence of coliform bacteria, which are lactose fermenters. After the necessary confirmatory tests, the result is recorded as positive or negative. The most probable number (M. P. N.) of coliform bacteria is determined from the numbers of tubes giving a positive result with different volumes or dilutions of the original sample. The principle underlying this method of enumeration is based on the theory of probability, a given result having a definite maximum probability that a definite number of coliform bacteria per unit of volume (i. e., a milliliter or 100 milliliters) is present in the sample tested. Although this method is subject to a considerable error in single determinations, it probably affords the most logical and relatively precise one available for determining small densities of coliform bacteria from fermentation tests.

(3) *Direct plate enumeration of coliform bacteria.*—This method, originally developed in its present form by Noble and Tonney, utilizes the plate-count procedure described above under B (1), but depends on the use of a culture medium which is selective for bacteria of the coliform group. Experience with its application to a large number of water examinations in the present survey has indicated that it gives average results which agree fairly well with those of the fermentation test, though individual results may show considerable divergence. The relative precision of the direct count seems to vary to some extent with the density of coliform bacteria present in the sample and also with the number of countable colonies on the plates. A certain degree of skill, resulting from experience, is necessary for the identification of colonies on the plates which are typical of coliform

bacteria. The culture medium is only partly selective as it permits the growth of a limited range of noncoliform species.

Additional tests of a special nature, made only on certain samples, have included nitrite, nitrate, acidity to phenolphthalein (hot and cold), and total hardness. In some cases routine tests for turbidity and alkalinity have been limited to samples from certain key points. Biological tests have been carried out as indicated in the section of this report devoted to the biological survey work (appendix 1, memorandum No. 8).

From time to time it has been desirable to examine certain types of industrial wastes concerning which little has been known of their composition and more especially as to their suspended and volatile matter content and biochemical oxygen demand. These tests have been made as required, both at the base and at the mobile laboratories.

During the year 1940 considerable numbers of samples of bottom mud deposits collected from the Ohio River were examined at the Cincinnati base laboratory. The tests made on these samples included biochemical oxygen demand after 2, 4, 6, 8, and 10 days, total and volatile matter, moisture content, and amounts of potassium permanganate and bichromate consumed under standard time and temperature conditions.

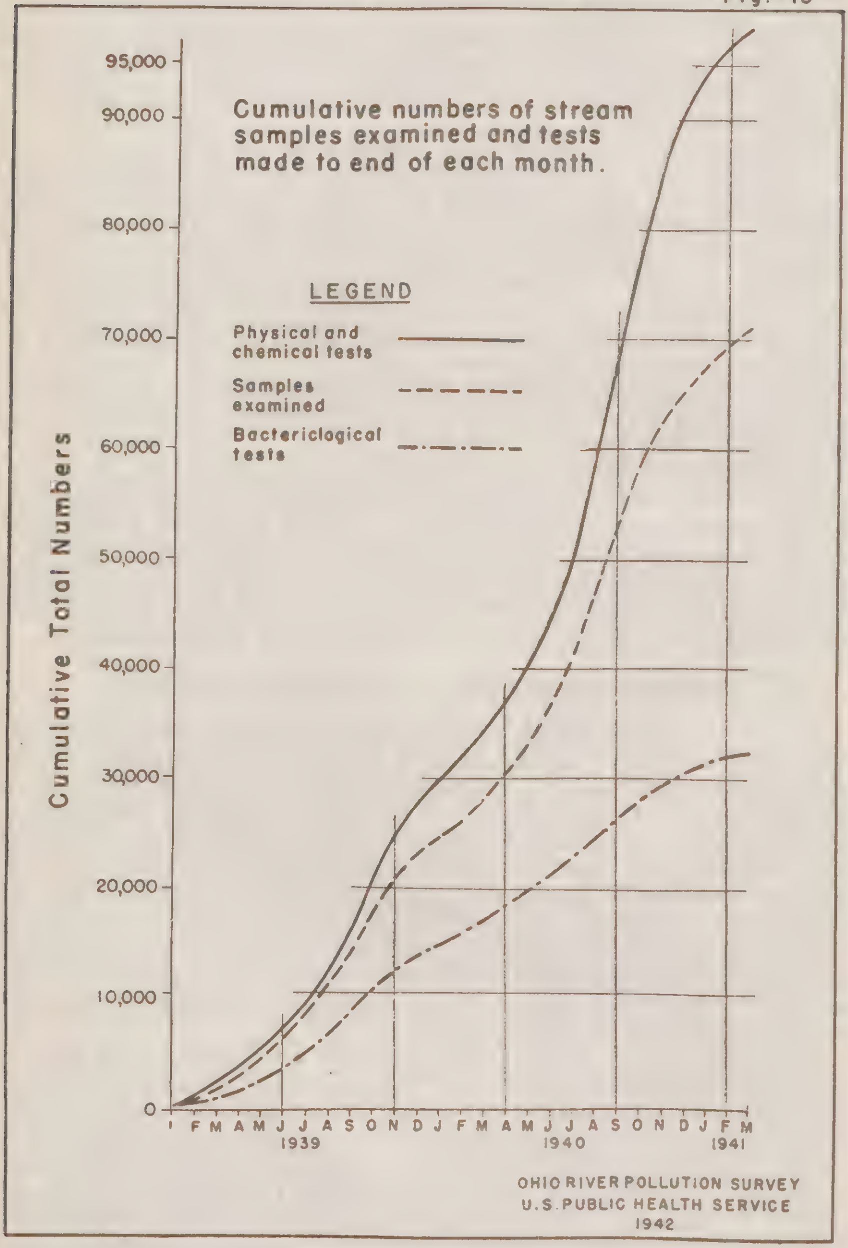
In connection with the mobile laboratory operations, a regular practice was made of examining bacteriologically the more important public water supplies of communities visited by these laboratories. At the Kiski laboratory and in connection with the special study of taste and odor difficulties in water supplies along the Mahoning and Beaver Rivers, numerous routine tests for phenol content were made on stream waters suspected of being involved in these difficulties.

Summary of Routine Laboratory Operations

Up to the end of March 1941, when routine laboratory operations were terminated, a total number of 71,124 water samples had been collected and examined in connection with the Survey, exclusive of samples examined biologically. The total number of examinations made on these samples was 131,132, of which 98,554 were physical and chemical tests and 32,578 were bacteriological examinations. The average number of samples examined during the 26 months of the laboratory operations was about 2,640 per month, with a maximum number of 6,570 in August 1940, when operations were at their highest intensity. The number of laboratory tests averaged about 5,000 per month for the entire period of the Survey and reached a maximum number of 11,420 in August 1940.

In figure 15 are shown graphically the total number of samples examined and tests made up to the end of each successive month, beginning with January 1939, when a few samples were collected from the Ohio River at Cincinnati. The effect of winter curtailment of the stream examinations, owing to adverse weather conditions, is apparent in the trend of the curves during the December–February period of 1939–40. Part of the lag in the upward trend of the curves shown for this period was due, however, to the reorganization incidental to carrying out the accelerated plan of operations adopted in Feburary 1940. The lag near the end of the survey period indicates the effect of curtailing operations gradually, beginning in October 1940.

Fig.-15


Cumulative numbers of stream samples examined and tests made to end of each month.
LEGEND
Physical and chemical tests
Samples examined
Bacteriological tests
Cumulative Total Numbers
95,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
J F M A M J J A S O N D J F M A M J J A S O N D J F M
1939
1940
1941
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

On the basis of records maintained throughout the progress of the survey, the average amount of work performed by one mobile laboratory unit per month was as follows:[7]

	Mobile laboratories	Kiski laboratory	Cincinnati laboratory
Cost per sample	$2.78	$2.26	$1.79
Cost per test	1.22	1.13	1.09

The somewhat higher unit cost of operating the mobile laboratories was due mainly to the conditions of their operation, which necessitated moving them from place to place about every 2 weeks, thus entailing some degree of interruption in the work, whereas the base laboratories were operated on a continuous schedule, with no interruptions due to extraneous circumstances. Another important element in the higher cost of operating the mobile laboratories was the added expense of maintaining their personnel in the field, which included an extra per diem allowance for subsistence. The base laboratory personnel were located at fixed stations and did not receive such an allowance. In the absence of this added item of expense, the mobile laboratories would have shown a considerably lower unit cost of operation, because less capital and upkeep expense was involved in providing and maintaining them. This type of laboratory was found to possess many practical advantages over those of fixed location in covering a large and varied stream area. It was in some respects the most valuable new device for facilitating stream pollution surveys which was developed in the present survey.

Personnel

The laboratory operations of the Survey were performed under the administrative direction of Sanitary Engineer Director J. K. Hoskins, in charge of the Stream Pollution Investigations Station at Cincinnati, who was succeeded in July 1940 by Medical Director H. E. Hasseltine. The work was organized and carried out under the technical direction of Sanitary Engineer Director H. W. Streeter, with Biologist F. J. Brinley in immediate charge of biological studies, Public Health Engineer C. T. Carnahan and Passed Assistant Sanitary Engineer F. E. DeMartini in charge of mobile field laboratories, and Public Health Engineer S. G. Monroe in charge of the floating base laboratory *Kiski*. Principal Bacteriologist C. T. Butterfield, Principal Chemist C. C. Ruchhoft, Special Expert W. C. Purdy, and Senior Biologist J. B. Lackey, all from the regular staff of the Cincinnati station, cooperated actively in training the laboratory personnel, preparing instruction memoranda on laboratory methods and in acting as technical advisors in various phases of the work. Passed Assistant Sanitary Engineer (R) C. L. Chapman was in charge of the special acid stream work based at Morgantown, W. Va. The six mobile laboratories were under the immediate charge of Junior Chemists Stuart Cohen, Stephen Megregian, F. M. Middleton, F. I. Norris, O. G.

[7] Figures taken from article by F. E. DeMartini, previously cited.

Pettijohn, and R. A. Snider. The laboratory work at the *Kiski* laboratory was performed by Assistant Chemist W. W. Walker and Bacteriologist B. S. Levine, and at the Cincinnati laboratory, by Assistant Chemist M. B. Ettinger and Junior Bacteriologist C. W. Chambers.

Acknowledgments

The laboratory work of the survey was carried out with the active collaboration and assistance of several agencies which were most helpful in reinforcing the work of the regular staff. In the biological work, active collaboration was furnished by the laboratory of Interior Fisheries Investigations, United States Bureau of Fisheries, under the direction of Dr. M. M. Ellis, in examining numerous fish specimens as to their physiological condition and preparing a report of this work which is included as appendix to the general report of the biological investigations. (See supplement F, to the main report of the survey.) Cooperation in the biological work on fish life also was given by the Ohio Division of Conservation through Messrs. E. L. Wickliff and M. B. Trautman of that staff. The laboratory of the Dayton, Ohio, sewage treatment plant, under the direction of Mr. M. W. Tatlock, carried out systematic examinations of stream waters in that vicinity as a direct contribution to the work of the survey. The laboratories of the Tennessee Valley Authority and the Tennessee Department of Health made available the results of their extensive stream analyses in the Tennessee and Cumberland River Basins, respectively. To all of these agencies and individuals grateful acknowledgment is due for their generous cooperation, which greatly facilitated the work of the survey and made possible certain economies in the scope of operations. Acknowledgment also is due to the various municipal officials, too numerous to mention here, who assisted in providing location places for the trailer laboratories during their field operations, and to the State sanitary engineering divisions which facilitated these arrangements. Finally, special acknowledgment should be made of the courteous assistance furnished by the offices of the Ohio River Division and of the district engineers, Corps of Engineers of the United States Army, in arranging for the collection of river water samples at the navigation dams in the Ohio River and for the provision of various services and material supplies in connection with the operations.

APPENDIX I

LABORATORY MEMORANDA

CONTENTS

MEMORANDUM NO. 1 (DECEMBER 15, 1938)

COLLECTION OF RIVER WATER SAMPLES AT UNITED STATES LOCKS AND DAMS

The following instructions have been prepared for the use of United States Engineer Corps personnel who may be assigned to the regular collection of river water samples at the Ohio River locks and dams and at the mouths of certain tributaries.

SAMPLING EQUIPMENT

The regular sampling equipment (sampler will consist of a bronze subsurface collecting vessel, fitted with a rope for lowering and raising the vessel and a heavy cord for operating the release cock). The hoisting rope will be marked at 5-foot intervals with colored twine. It is assumed that the collector will be provided with a skiff and outboard motor for use in collecting the samples.

The sampler is fitted with a cover, gasket, and thumbscrew lugs for tightening the cover in place. A raised platform inside the sampler is provided with clips for holding three bottles. Two of these bottles are identical in shape and size, being intended for collecting duplicate samples for dissolved oxygen and biochemical oxygen demand tests. The third bottle (sterilized) is for the bacterial sample. In the cover of the sampler are tubes located so that they may be extended down into the three bottles when the cover is in place. One of these is a sterilized glass tube for the bacterial sample bottle. This tube will be changed for each collection. When the cover is locked in place, the tubes will project down into the bottles through their open mouths, the stoppers being removed when placing the bottles into the clips. A supply of bottles, with carrying cases, and glass tubes will be furnished the collector in advance.

LOCATION OF SAMPLE COLLECTION POINTS

Pending the more exact location of sampling points in the river and establishment of ranges for locating these points, samples will be collected at three points on a cross-sectional line extending across the channel about 500 feet upstream from each dam and in a direction parallel to the dam. One of the three points will be located approximately midway across the stream and the other two at points located approximately midway between this center point and the shore in each direction. An effort will be made to obtain each sample at about middepth in the stream; that is, at a point about midway between the surface of the water and the bottom of the channel.

As soon as possible after the regular collection of samples has been started, United States Public Health Service engineers will locate permanent sampling cross sections above and below each dam and will establish on each cross section convenient range lines whereby the collector will be able to locate himself readily on each point. At the same time soundings will be made to establish the river depth at each point corresponding to pool stage or to some other known stage of the river and the corrected depth at other stages can then be determined by adding or subtracting one-half the number of feet which a given river stage is above or below the reference stage (i. e., pool or otherwise). Temporarily, the depth at each point can be established roughly by sounding with the collecting vessel, or with a sounding line, and then bringing the vessel to about one-half this depth.

METHOD OF COLLECTING SAMPLES

Before starting the collection each set of three sample bottles will be marked as "R," "C," or "L," denoting respectively the right, center, and left points along the cross section, facing downstream. In reaching the first point, whether it be the right (R) or left (L), the three bottles thus designated will be placed in the clips in the sampler with their stoppers removed (and remaining tied to the necks of the two identical bottles). The bacterial bottle will be wrapped in paper as delivered to the collector and will be sterilized before delivery, as it is intended for collecting a sample for bacteriological examination. The stopper of this bottle will be covered with tinfoil, which should not be removed in taking out the stopper. In handling this bottle and its stopper, the greatest care should be taken by the collector not to touch with his fingers or anything else the inside of the bottle neck or the corresponding outer face of the ground-glass stopper, or to lay the stopper down so that this face comes in contact with any surface. The object of this precaution is to prevent any contamination of the sample bottle from an outside source during collection of the sample.

The stopper should be handled with the tinfoil cover in place, so as to facilitate protecting it from contamination. In inserting the sterilized glass tube for this bottle into the cover of the sampler, similar precaution should be taken not to allow the fingers to come into contact with the tube. By removing only a part of the wrapper from the tube, the bare end can be inserted in the cover by holding the covered end in the fingers.

After the bottles have been placed in the clips and the glass tube inserted in the cover, the cover is then placed on the sampler with the tubes projecting into the bottles, the thumbscrew lugs tightened into place, and the air-release cock closed, with the handle turned to a horizontal position. The sampler is then lowered to mid-depth and the air-release cock opened by pulling the auxiliary cord. Water then will flow into the sampler until the air vent is trapped by the short tube. When the flow is stopped, the two duplicate bottles should be completely full and the third (bacterial) bottle, one-half to three-fourths full. During the filling operation, displaced air from inside the sampler will escape and appear at the surface of the river as bubbles. As soon as this air bubbling ceases, the vessel is ready to draw up to the surface and be lifted into the boat (it should be kept in a vertical position so far as possible while lifting it into the boat).

After removing the cover, the single bacterial sample bottle is removed first and its contents brought down, if necessary, to a level of about three-fourths full. The stopper is inserted with the same precautions against contamination by the fingers as above noted. This sample is then wrapped in its paper, with the tinfoil cover in place, and placed vertically in the carrying case. The two duplicate bottles are then removed, completely full, and their stoppers inserted so as not to allow any air to be trapped under them in the neck of the bottle. If water should be spilled from these bottles while removing them from the sampling vessel, they should be filled to the top with water drawn from the sampler with a glass pipette, before inserting the stoppers. These bottles, with their stoppers tightly inserted, will then be placed in the carrying case and the collector will proceed to the next sampling point, where the same operations as above described will be repeated.

TRANSPORTATION OF SAMPLES TO LABORATORY

As a rule, the samples after collection will be taken by the collector to a designated point near the dam and there picked up by the United States Public Health Service collector, who will transport them in his automobile to the laboratory. As the automobile transportation route will follow the right (Ohio-Indiana) bank

of the river, arrangements will be necessary for delivering the samples to convenient points along that side. As soon as the automobile transportation has become established the collection of the samples from the river can be timed so as to involve a minimum of delay between the time of collection and the time of being taken up for transportation to the laboratory. Ordinarily, the working schedule will provide for the collection of a set of samples once each working day, or every other day, at some time between 3:30 a. m. and 9 a. m., depending on the distance of a particular dam from the laboratory and its position on the automobile transportation route. After this time has been established, it will be subject to little if any variation from day to day. During the warmer season, the samples after collection will be placed and kept in iced containers (to be provided by the laboratory) from the time of collection to the time of reaching the laboratory. This precaution is necessary in order to prevent multiplication of bacteria in the samples, with corresponding changes in their numbers, during transportation to the laboratory.

When stopping at each dam for the samples, the United States Public Health Service collector will leave a complete set of sample bottles with containers for the next collection. As a rule, an extra set of bottles will be kept at the dam for use when for any reason a set may not be delivered in time for the next collection. Each sample collector will be provided with a complete set of river sampling equipment which he will keep in a convenient place at the dam.

SPECIAL SAMPLES

Occasionally, in order to meet the needs of the laboratory work, it will be necessary to request an extra sample of river water for transportation to the laboratory. Samples of this nature usually can be supplied from the surplus water in the sampler, using extra glass containers which will be furnished by the laboratory.

At certain dams, it will be necessary occasionally to request the collection of two sets of samples at one time, one being collected above the dam, as usual, and the other at least one-half mile below the dam (so as to remove the effect of any entrained air). Where the mouths of important tributaries are located near dams, regular collection of a single midpoint sample from these tributary mouths may be requested, in addition to the set of samples from the main stream.

At some dams, notably Nos. 27, 29, 31, 37, and 38, a study will be undertaken of the nature of sludge deposits preceding and during periods of low water, when the effects of sedimentation will be most apparent. In this connection, it may be necessary to request the occasional collection of mud samples from the river bottom, using special equipment which will be provided by the laboratory. This will not entail any material increase in the time required for the collector's services, as collection of these samples can be made at the same time as that of the regular river water samples. It will involve no difficulties other than the occasional handling of the mud-collection equipment.

APPENDIX—MEMORANDUM NO. 1

DETAILED INSTRUCTIONS TO SAMPLE COLLECTORS

1. For collecting one complete set of samples of river water on a cross-section of the river, the following equipment will be provided to each collector:

- (*a*) One deep-water sampler with lid, gasket, inside platform with clips, hoisting rope marked at 5-foot intervals, and air-release valve with separate operating cord.
- (*b*) Nine bottles, of which six are narrow-mouth, unwrapped, and three are wide-mouth, wrapped (sterilized).
- (*c*) An extra supply of bottles in case of breakage; also any extra bottles for special samples as required.
- (*d*) Sterilized glass tubes in wrappers.
- (*e*) A water temperature thermometer, mounted in a nonbreakage rod.
- (*f*) A glass pipette and funnel.
- (*g*) Carrying case for sample bottles and samples.

2. For the ordinary collection, a set of three bottles will be collected at each one of the three points on a river cross section. For convenience, these three points will be designated by the letters (R), (C), and (L), denoting respectively the right, center, and left points on the section, facing downstream. Each set of three bottles will consist of two narrow-mouth bottles (duplicates) and one wide-mouth bottle. Each set should be marked with its proper letter corresponding to the point of collection.

3. Locations of (R), (C), and (L) points will be furnished each collector in advance, mainly by means of shore ranges whereby he may locate himself on a given point in a boat under any river condition. Pending more exact location of these ranges, samples will be collected on a cross section located about 500 to 1,000 feet above each dam, the (C) point being about halfway across the channel and the (R) and (L) points midway between the (C) point and the shore in either direction. Samples at each point will be collected at approximately mid-depth. Temporary ranges for these cross sections will be established for the collectors, using two prominent landmarks, one on each side of the river, lined approximately at a right angle to the direction of the flow.

4. Before proceeding to the first collection point, the collector should place a set of three bottles in the sampler clips and insert a fresh sterilized glass tube into the hole provided on the under side of the sampler cover. Before placing the bottles the stoppers should be removed, those in the duplicate narrow-mouth bottles being left tied to the bottle neck and the stopper of the wide-mouth bottle being carefully removed with the tinfoil in place and inverted resting on its top at some convenient place in the boat.

Caution.—In handling the wrapped wide-mouth bottle, do not allow the fingers to touch the inside of the bottle or its neck, or the ground face of the stopper. Save the wrapper for wrapping the sample after collection. In inserting the glass tube, do not allow the fingers to touch the tube itself. Handle one end with the wrapper in place, inserting the bare end.

5. With the bottles in place, the cover is then set on the sampler, with the two metal tubes projecting down into the narrow-mouth bottles and the glass tube into the wide-mouth bottle. Tighten the cover securely by means of the six thumbscrew lugs, with the gasket in place, so as to make a tight joint. The air-release valve should be closed, with its handle in a horizontal position.

6. The sampler is next lowered over the side of the boat into the river, being careful not to allow the air-valve cord to become fouled with the hoisting rope. Using the 5-foot markers, the sampler is lowered to about mid-depth and while held in this position the air-valve cord is pulled smartly, so as to open the valve. As soon as this valve is open, water will flow into the sampler through the tubes and fill the bottles by several displacements, the air escaping through the air valve and appearing as bubbles at the surface. As soon as these bubbles have stopped coming up to the surface, the sampler may then be hoisted back into the boat.

7. With the filled sampler in the boat remove the cover and place the thermometer in the water in the vessel, leaving it there for a later reading. Next, take out the wide-mouth bottle, which should be about three-quarters full, insert the stopper carefully and restore the wrapper, being sure that it is properly marked with the letter designating the point and the number representing the location of the cross section (this number will be furnished to the collector). Then remove the two narrow-mouth bottles, which should be completely full, and insert their stoppers so that no bubbles of air will be left in the bottle under the stopper. If the bottle is not completely full, draw a little water from the sampler vessel with the pipette and fill it in this way. Then read and record the temperature of the water as shown by the thermometer.

8. From the surplus river water left in the collector, remove enough to make up any special sample required and pour the rest overboard. A glass funnel will be furnished for use in pouring water from the sampler into an extra bottle if required.

9. Now proceed to the next two points and repeat operations (4), (5), (6), (7), and (8) at each point.

10. After each collection, place the samples in the carrying case, being sure that they are marked properly. Place the discarded glass tubes in the case and secure the cover of the case, ready for transportation to the designated point on the shore.

11. After finishing the day's collection the sampler should be flushed out with clean water, the metal tubes and cover wiped clean, and the rope and cord coiled neatly, ready for the next collection. The sampler and other equipment should be stored at a suitable place near the boat mooring. Directions will be given each collector as to where the carrying case containing the samples should be delivered after collection.

12. During the warm season, provision may be necessary for packing the samples in an iced container for transportation to the laboratory. These arrangements will depend on circumstances and on the availability of a small amount of ice locally. The iced containers will be furnished from the laboratory, when their use is necessary.

13. In collecting samples from tributaries, where required, a single point in the middle of the stream will be used, rather than three points as in the main river. Samples will be collected at mid-depth in tributaries as in the main stream.

MEMORANDUM No. 2 (DECEMBER 29, 1938)

PLAN AND OBJECTIVES OF LABORATORY SURVEY

This memorandum has been prepared especially for the information of new personnel who have not been connected with previous work of the United States Public Health Service and have not been acquainted with the history, plan, and objectives of the present survey of pollution of the Ohio River and its tributaries. It is hoped that through this medium those who will be actively engaged in the work, and especially in its laboratory side, will be enabled to gain a better perspective of the work as a whole and of the respective parts which they will play in it. It is only through such an understanding that individual effort may be intelligently directed to the particular work in hand and that a sense of pride and "esprit de corps" may be developed among those who will be collaborating in the very considerable task that lies ahead.

HISTORICAL BACKGROUND OF PRESENT SURVEY

In the year 1912, an act of Congress extended the functions of the Public Health Service and authorized investigations of "the diseases of man and conditions influencing the propagation and spread thereof, including sanitation and sewage and the pollution, either directly or indirectly, of the navigable streams and lakes of the United States." In 1913 a special appropriation, continued annually since that year, was made for carrying out these provisions, including investigations of stream pollution. In the summer of 1913 work was begun on a study of the pollution and natural purification of the Ohio River, which was selected as a typical large inland stream receiving sewage, mostly untreated, and also used very largely as a source of public water supplies. This study was continued until the end of 1916.

At the time of this study, little was definitely known concerning certain fundamental quantitative relationships which are involved in the pollution and self-purification of rivers. The main objective of the study was to obtain some basic observations bearing on those relationships, such as the ratios of measurable sewage pollution to numbers of contributing population, the polluting effects of certain industrial wastes in terms of quantities of manufactured products and of equivalent sewage-contributing populations, and the various effects of time, temperature, pollution density, etc., on observable rates of natural purificaton of sewage-polluted streams. Incidentally, a fairly comprehensive general picture was obtained of the status of pollution of the Ohio River proper in zones extending below certain major centers of pollution, such as Pittsburgh, Wheeling, Cincinnati, and Louisville, and also of the more important tributaries at their points of entry into the Ohio. The observations did not extend to all sections of the Ohio River or to any of its tributary streams except at their mouths.

Interrupted by the World War, stream-pollution activities of the Public Health Service were resumed in 1921 with a study of the Illinois River, followed by surveys in the upper Mississippi, the lower end of Lake Michigan and, in 1930–31 a resurvey of that portion of the Ohio extending from above Cincinnati to below Louisville. Although these several investigations indicated conditions of pollution in the waterways concerned, they were primarily research projects designed to throw further light on the more basic problems of river sanitation. These field studies have been supplemented by basic research work at the Cincinnati laboratory dealing with certain problems of water and sewage purification closely allied with those of stream pollution. In this category have been studies of the efficiency and limitations of water purification and of the mechanism of sewage oxidation by activated sludge.

THE PRESENT SURVEY

The present survey has resulted from the River and Harbor Act of August 1937, section 5 of which provides that the Secretary of War is authorized and directed "to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited, directly or indirectly, therein and

the sources and extent of such deposits and with a view to determining the most feasible method of correcting and eliminating the pollution of these streams." It is also provided in the act that the survey shall include comprehensive investigations of the various problems relating to stream pollution and its prevention and abatement; that cooperation and assistance of the Puvlic Health Service may be secured, that a report shall be made to Congress with recommendations for remedial legislation, and that the expenses of the survey shall be paid from current appropriations for rivers and harbors work.

Shortly after passage of this act, a request for active collaboration in the survey was received and accepted by the Public Health Service. As the result of preliminary conferences it was agreed that the Public Health Service would carry out the following parts of the study: (1) Necessary laboratory studies, chemical and biological; (2) collection and study of factual data relative to pollution; (3) determination of the character of water in the main stream and its tributaries; (4) determination of the extent of treatment of polluting material required; and (5) all other investigations necessary to determine existing conditions and, as far as possible, future conditions which may have bearing on the pollution problem. A lump-sum allotment of funds has been made to the Public Health Service by the War Department for carrying out this general program of work, a portion being made available for the current fiscal year.

PROJECTED WORK FOR THE CURRENT YEAR

For the current year, the proposed work will consist of—

1. Laboratory studies of the Ohio River proper between the mouth of the Kanawha and the mouth of the Kentucky River to determine existing conditions of pollution.
2. A study of the extent and effect of organic sludge deposits in the existing pools and especially in those formed by permanent dams.
3. Laboratory study of streams in the coal mining area to determine the amount of acid and acid salts carried by the river.
4. Surveys of the tributary streams entering the Ohio River between the Kanawha and Kentucky Rivers to determine the extent of pollution and remedial measures necessary.
5. Continuing surveys of the pollution of the Tennessee and Cumberland Rivers now under way, in cooperation with the Tennessee Valley Authority and the State Department of Health of Tennessee.

SURVEYS OF SOURCES OF POLLUTION

The work of the survey has divided itself quite naturally into two main sections, one consisting of field surveys of sources of pollution and the other, laboratory surveys of the streams. The first section of the work, which is being organized as a separate project under Mr Crohurst and Mr. Tisdale, will involve the systematic collection of data from state departments of health and other agencies bearing on sewered populations along the various streams, the amounts and kinds of wastes discharged by industries, the extent of sewage and industrial wastes treatment and allied matters. This survey also will disclose the locations of stream zones in which conditions of pollution are bad or unsatisfactory, thus pointing toward areas which may require some degree of laboratory study. It also will be concerned with the collection of basic data for later engineering studies of the interception and treatment of sewage from various areas of pollution.

HYDROMETRIC DATA

An essential part of the basic data for a survey of river pollution consists of detailed information bearing on the volumes of flow of a main stream and its tributaries, not only throughout the period of the survey, but also during a term of previous years, in order to establish the relative normality of various flows encountered during the survey period and to provide a basis for estimating future conditions of pollution under average or extreme flows such as experience may have shown are likely to occur.

One of the three major sections of the survey will be an extensive compilation of stream-flow data for the Ohio and its main tributaries, to be furnished by the United States Engineer Corps through the office of the division engineer at Cincinnati, Col. E. H. Marks, and under the general and immediate direction of Capt. P. N. Strong and Principal Engineer R. L. Bloor, respectively. This work will

consist of the analysis of past-flow records, showing the average and the 7-day minimum flows during each month of a term of years extending back from 1938, and also the compilation of daily flows, covering the entire period of the present survey, at a series of gaging stations located on the main stem of the Ohio River and at strategic points on its main tributaries. The work of obtaining these data will be aimed especially at showing average and minimum low-water flows, though the entire range of variations will be recorded for the period of the survey.

The very comprehensive data thus made available will be used as the basis of interpreting the laboratory observations in the various streams, both in showing the total quantities of polluting substances per day carried by them at different sampling points and in indicating the degree to which the observations will have to be corrected so as to convert them to terms of normal or minimum flow conditions for the purpose of estimating present or future requirements as to corrective treatment of polluting wastes.

Laboratory Surveys

The first part of the laboratory surveys to be organized is that which deals with observations of pollution conditions in the main stem of the Ohio River, these observations being confined during the current year to the Kanawha-Kentucky River section, which comprises a length of about 280 miles along the middle third of the Ohio River proper. The lower half of this stretch, extending from dam 33, near Maysville, Ky., to the mouth of the Kentucky River at Carrollton, Ky., will be covered from the laboratory at Cincinnati, where the analytical work will be performed. The upper half, extending from dam 33 upstream to dam 25, near Point Pleasant and above the mouth of the Kanawha River, will be covered by a floating laboratory which is being installed on the United States quarterboat *Kiski*, which has been loaned for the purpose by the United States Engineer Corps as a very substantial contribution to the laboratory work of the survey.

In the Maysville-Carrollton stretch, the section extending from dam 36 to dam 37, in which heavy pollution enters from the Cincinnati metropolitan district, will be studied more intensively than the remainder of this stretch. In the Point Pleasant-Maysville stretch, the section extending from Huntington to Portsmouth will receive similarly intensive study, as pollution is heavy in this area. In the Cincinnati pool, 9 regular sampling stations have been planned, depending on the availability of motorboat sample collection, and in the Huntington-Ironton section, 10 stations have been planned, depending similarly on motorboat collection. Above and below these two respective sections of the river will be sampling stations more widely spaced and located mostly at Government locks. Arrangements are being made for regular collection of samples by the lock personnel and their transportation to the laboratory by Public Health Service collectors, using automobiles. This collection service has been made possible through the courtesy of the United States Engineer Corps, who have offered the excellent facilities of the Government lock personnel and equipment for this purpose.

Routine Laboratory Determinations

The routine schedule of river-water examinations will include the following determinations: (1) Temperature, (2) turbidity, (3) alkalinity, (4) dissolved oxygen, (5) 5-day biochemical oxygen demand, (6) bacterial count, 24 hours at 37° C., and (7) coliform group index. Determinations (2) and (3) will be made on samples collected only at one or two key stations from each laboratory. An effort is being made to ascertain whether it will be feasible to substitute gradually a direct-plate count for coliform bacteria instead of the usual enumeration based on fermentation tube tests. In order to establish when the use of modifications of the Standard Winkler procedure will be necessary in making dissolved-oxygen determinations, semiroutine determinations of nitrite and also possibly ferrous and ferric iron will be necessary. Special determinations in the river water will be needed occasionally for pH, CO_2, and acidity, particularly in waters affected by mine drainage and steel mill wastes.

In studying the extent and nature of organic sludge deposits above certain dams, arrangements will be made for the regular collection of samples of these deposits by the Government lock personnel at intervals of 1 or 2 weeks during periods of low water and following periods of freshets. The primary object of these tests will be to ascertain the extent to which organic deposits are formed in the river during low stages and the extent to which they are removed by scouring action during freshets. In this connection, special attention will be given to

sludge deposits formed above the higher permanent dams, of which two have been constructed in the upper section of the Ohio. Considerable question exists as to whether deposits are completely removed by freshets from the pool, formed by these higher permanent dams, or whether there will be a tendency for these deposits to accumulate from year to year as the result of incomplete removal. Changes in the character of the deposits from low- to high-water periods can be gaged by tests of their total biochemical oxygen demand or oxidizability and indicators such as the percentage of volatile solids when figured on a dry basis.

Another special field of tests which can be carried out at the Cincinnati and floating laboratories will deal with the character of sewage and certain industrial wastes which may be important factors in the pollution of the river. These tests will necessarily be curtailed to the minimum essential requirements, such as total and volatile suspended matters, settleable solids, and biochemical oxygen demand. Data of this kind will be highly desirable later in considering requirements and possibilities for sewage and industrial wastes treatment at different points. An important problem to be considered in this connection will be the possibilities for treating certain highly organic industrial wastes in combination with sewage.

Tributary Studies

Draining into the Ohio River between the mouths of the Kanawha and Kentucky Rivers are several important tributaries, including the Guyandotte, Big Sandy, Scioto, Little Miami, Licking, and Miami Rivers. During the coming year an effort will be made to observe the sanitary condition of these tributaries in their more highly polluted sections, except in the Scioto, where an organized study has been in progress for more than a year past.

At the present writing, two alternative methods of making these observations are being considered. One would consist in operating one or more completely equipped mobile laboratory units, using automobile trailers or trucks, which would travel among the tributaries and collect and examine samples of river water and any important industrial wastes. Mobile units of this kind would be equipped for complete field examinations of samples, including determinations of dissolved oxygen, biochemical oxygen demand, 37° C. bacterial count, and coliform group index. The alternative plan would involve using ordinary automobiles equipped with kits for certain tests, such as dissolved oxygen, pH value, and alkalinity or acidity, which could be readily made in the field. Samples for more complete examination would be collected and tested at nearby water or sewage laboratories connected with treatment plants. The latter method may be preferable if a sufficient number of plant laboratories are available for the necessary, more complete tests.

TESTS OF ACID MINE STREAMS

Owing to the fact that neither of the two base laboratories will be located in the areas most affected by acid mine wastes, it will not be practicable to undertake any extensive observations of streams in these areas during the coming year, except in the Kanawha region, where an effort will be made to develop some systematic field observations based at the floating laboratory *Kiski* in order to provide a ground work for more extensive observations, it is planned also to set up, under a part-time compensation arrangement, some stream observations based at Morgantown, W. Va., at Norris, Tenn., at Pittsburgh or McKeesport, Pa., and possibly at a fourth point to be selected after consultation with the director of mine-sealing operations in these and other areas. The object of these observations will be to show acid conditions prevailing in some of the larger representative streams draining mining regions, in which fairly extensive mine-sealing operations have been completed and others draining nearby areas in which little or no mine-sealing has thus far been undertaken.

Conclusion

The essential difference between the present survey and those which have been made previously by the Public Health Service is that it will be concerned primarily with the more practical measures which may be necessary to correct undesirable conditions of stream pollution, wherever they may be known or found to exist in the Ohio River Basin, whereas the previous surveys have dealt primarily with establishing certain basic relationships and constants which underlie the pollution and natural purification of streams in general. The distinction here involved is that which may be said to exist between a practical situation and its specific remedy and a more general research problem, with its broader implications.

In the present instance the effort thus will be directed mainly to ascertain where actual conditions of pollution are undesirable and, wherever those conditions are observed, to establish a basis for estimating from the known facts concerning sources of pollution, the extent of corrective measures which may be necessary. In some cases the most important consideration involved may be excessive burden on water purification plants. Here the bacteriological and biological evidence will assume a primary role. In other cases it may be an undue burden on the oxygen resources of the stream, affecting the maintenance of normal aquatic life, the use of the stream for recreational purposes, and, perhaps, even the general prevalence of nuisance conditions in the adjoining riparian areas. In this latter instance a study of the oxygen balance relationships and their restoration to a favorable status will be a primary consideration. Thus, it is evident that each local area of pollution will have to be studied more or less as an individual problem and the stream observations adjusted accordingly. Although detailed study of many such areas will be impracticable, in view of the limitations of available time and personnel, it should be possible to locate these areas and to show at least roughly where and to what extent corrective measures will be needed. The survey will afford an unparalleled proving ground for methods of evaluation which have been developed from previous studies of similar problems. It will be, in a sense, a new pioneering adventure, full of interest and action for those who will participate in it.

Memorandum No. 3 (December 29, 1938)

Instructions for Routine Bacteriological Examinations

In conducting the bacteriological examinations for the Ohio River pollution survey, the procedure given in Standard Methods for the Examination of Water and Sewage, Eighth Edition, 1936, of the American Public Health Association shall be followed. In cases where choices of equipment, material, or procedure are offered, or where interpretation of the procedure given seems desirable, or where a deviation from the Standard procedure is to be made, the considerations which follow shall apply. Any deviations from the Standard procedure will be in the nature of an increased requirement employed as a safety factor.

Sample bottles.—Eight-ounce ground-glass stoppered wide-mouthed bottles shall be used.

Pipettes.—The 1.0 milliliter pipettes shall be graduated in 0.1 milliliter and the spacing for the 0.1 milliliter portion shall be at least 0.5 inch.

Dilution bottles.—Glass bottles with tight-fitting cotton plugs and paper caps will be used, (observing the precautions cited in Standard Methods), unless the newly described rubber stoppers prove satisfactory after trial in the central laboratory at Cincinnati. In using cotton-plugged bottles a circular motion of the mixture should be induced before vigorous mixing is started.

Petri dishes.—Side wall of Petri dishes shall be 15 millimeters high.

Fermentation tubes.—Durham type tubes shall be employed.

Hot-air sterilization.—Two hours at 170° C. shall be the required period and temperature.

Media.—Bacto dehydrated culture media as supplied from the central laboratory shall be used for all purposes. Effort has been made to secure sufficient media from one preparation mixture to last throughout the entire investigation.

Steam sterilization.—All media, other than special media which may be employed at times, for which special instructions will be given, shall be sterilized in the autoclave at 15 pounds live-steam pressure for 15 minutes, observing the Standard precautions for expelling air, etc.

Dilution water.—Phosphate buffered distilled water, prepared in accordance with instructions in Standard Methods, part III, section XII, paragraph 1.2, shall be used. The stock phosphate buffer solution will be supplied from the central laboratory. (See Public Health Reports 48:681, June 16, 1933, Reprint No. 1580, for justification of use of such water for bacteriological examinations.)

Dilutions.—The 99.0-milliliter portion of dilution water only, will be employed. Intermediate portions in a decimal series of dilutions will be obtained by measuring 0.1-milliliter portions directly from the sample or dilution thereof concerned. Experience has shown that, when this procedure is followed with precise technique, employing the 1.0-milliliter pipettes required above, the error involved is not as great as when attempts are made to provide and use exactly 9.0-milliliter portions of dilution water.

Shaking.—In shaking samples or dilutions of samples prior to withdrawal of portions for planting or further dilution, the agitation applied should be vigorous. An addition to the Standard requirement of shaking 25 times, that this be accomplished in 30 seconds when the bottle is moved each time through a space of at least 4 inches, has proved adequate.

Transfer of portions.—In transferring portions of a sample or of dilutions of a sample, a fresh sterile pipette of appropriate size should be used for each dilution. On introducing the pipette into the sample for the withdrawal of a portion, the tip shall not be allowed to descend into the sample or dilution thereof more than about 0.5 inch. This precaution is essential as occasionally samples are of such a nature that considerable material will adhere to the outside of the pipette and drain off with the measured portion when it is delivered. Similarly, when portions of a sample or dilution thereof are delivered to dilution bottles the polluted tip of the pipette should not be allowed to touch the neck of the dilution bottle as it enters or as it leaves the bottle. In making the delivery the tip of the pipette shall be brought into contact with the surface of the dilution water, but not allowed to descend into the water. With cotton plugged dilution bottles preliminary mixing of the sample with the dilution water should be accomplished before the cotton plug is wetted by the vigorous agitation specified.

In delivering portions of a sample or dilution thereof to Petri dishes the tip of the pipette should be allowed to touch the plate only once in making the delivery. Similarly, in delivering a portion to a broth tube the tip of the pipette shall be placed near the surface of the broth in the tube as delivery is made. This prevents erroneous results due to the adherence of portions of the sample or dilution to the sides of the broth tube above the level of the broth. Organisms cannot demonstrate their presence unless they are actually introduced into the broth.

Delivery from pipettes shall always be made from meniscus to meniscus. Delivery or blow-out pipettes will not be employed and in delivering portions the flow of the liquid shall not be speeded by jerking or blowing. In general, 1.0-milliliter pipettes will be employed for measuring 1.0- and 0.1-milliliter portions; 2.0-milliliter pipettes for 1.0- and 2.0-milliliter portions, never for 0.1-milliliter portions; and 10.0-milliliter pipettes only for portions larger than 1.0-milliliter.

Examinations.—The routine bacteriological examinations to be made on this survey will be (1) total counts of the number of bacteria growing on agar when incubated at 37° C., for 24 hours, and (2) an enumeration of the number of organisms of the coli-aerogenes group of bacteria. Additional special examinations or confirmations which may be instituted as the work progresses will be covered in subsequent memoranda.

Plating.—When the portion of sample or dilution thereof is added to the Petri dish no more than 15 minutes shall be allowed to elapse before fluid agar at the required temperature is added, thoroughly mixed with the portion and allowed to solidify.

In making plates, two plates containing duplicate portions of the water under examination, which will give colony counts within the prescribed limits, shall be made and also a third plate containing one-tenth or 10 times this amount, depending on whether in the judgment of the bacteriologist the count from the duplicate plates will be more than or less than the limiting number. If the number of colonies developing from the samples of a given station are so erratic that the results from the duplicate plates are frequently indeterminate, or if the sample is a new one from an unknown source, than more than one pair of duplicate plates should be made. In making counts of plates a standard illuminated counter will be used.

Supplemental instructions governing the prescribed limits for the permissible number of colonies per plate, the computation of the average bacterial count, and a list of the symbols employed in obtaining and recording results are appended to this memorandum.

Tests for members of the coli-aerogenes group.—Routine tests as made for this group of bacteria in this study will be limited to the results of the presumptive and confirmed test as given in Standard Methods. The confirmatory test for routine work will be limited to the demonstration of gas production in any amount in 48 hours in the liquid confirmatory medium employed, brilliant green bile (2 percent) lactose broth. A 3.0-millimeter loop will be used for the transfer from lactose broth to the confirmatory medium.

In making inoculations of primary lactose broth tubes for the determination of coli-aerogenes group organisms, three duplicate tubes at each of three decimal dilutions shall be planted. Dilutions for this planting should be selected so that

all of the three tubes in the lower dilution will be positive and all tubes in the higher dilution negative, with the results in the intermediate dilution variable. Whenever the results from a given station vary from this ideal to the extent that the results may be indeterminate, i. e., either all positive or all negative, then a fourth dilution should be added to the series of dilutions either higher or lower than the others, depending on the judgment of the bacteriologist. Only tubes of the highest dilution, showing gas formation in lactose broth, shall be transferred for confirmation, except that all tubes negative for gas after 24 hours of incubation, but positive for gas after 48 hours, shall be confirmed. A positive presumptive tube shall always be recorded as positive for the presence of members of the coli-aerogenes group of bacteria, unless confirmation has been tried. That is, the fact that a high-dilution tube has failed to confirm cannot be accepted as evidence that a lower-dilution gas-producing tube, prepared from the same sample, would also fail to confirm. Results obtained will be interpreted in terms of the most probable numbers of coli-aerogenes organisms present, in accordance with the tables given by Hoskins (Public Health Reports, 49:393, March 23, 1934, Reprint No. 1621). A copy of this reprint will be supplied to each bacteriologist.

Records.—When samples arrive in the laboratory pertinent data regarding them shall be entered in a serially numbered log book by the collector and the serial number written on the bottle. The serial number thus assigned to each sample will identify the sample and this number shall appear on each tube, plate, or record employed in connection with the sample. The pertinent data indicated should include adequate information regarding the source of the sample, the time of collection, the name of the collector and the temperature of the water at the time of collection. If any unusual conditions, which might affect either the sample or the environment at the point of collection, are noted, this information should be entered in the log under "Remarks."

All pertinent data concerning the sample and all results secured in connection with the bacteriological examination of a sample shall be entered on the record cards. No erasures shall be made. If an erroneous entry is noted it should be circled and if the correct result is known it should be entered at the nearest available space. The correct result thus entered should be O. K.'d by initialing.

RULES GOVERNING THE COMPUTATION OF THE AVERAGE SOLID MEDIUM BACTERIAL COUNT OBTAINED ON PLATES IN USE AT THE UNITED STATES PUBLIC HEALTH SERVICE STREAM POLLUTION INVESTIGATIONS LABORATORY, CINCINNATI, OHIO

1. Average for plate counts shall be based on plates which give counts in the range covered by 25 to not more than 400 colonies per plate.

2. When the duplicate plates in a series of three show between 25 and 400 inclusive, colonies per plate, and the third plate less than 25 or more than 400 colonies, the third plate should be omitted from the average unless it falls between the other two.

Examples

(*a*)

0.01 milliliter	92	
0.01 milliliter	76	
0.001 milliliter	6	(omit)
Result	8, 400	per milliliter.

(*b*)

0.1 milliliter	857	(omit)
0.01 milliliter	127	
0.01 milliliter	156	
Result	14, 100	per milliliter.

(*c*)

0.01 milliliter	92	
0.01 milliliter	76	
0.001 milliliter	9	(intermediate between duplicate parts)
Result	8, 600	per milliliter.

3. Where the duplicate plates both show too many or too few colonies, only the third plate should be considered in the average result.

Examples

(*a*)

0.1 milliliter	847	(omit; too many)
0.01 milliliter	732	(omit; too many)
0.001 milliliter	95	
Result	95, 000	per milliliter.

(*b*)

0.1 milliliter	65	
0.01 milliliter	8	(omit; too few)
0.01 milliliter	7	(omit; too few)
Result	650	per milliliter.

4. Where one of the duplicate plates gives an obviously erroneous count it should be disregarded in recording the average result.

Example

0.1 milliliter	68	
0.1 milliliter	29	(spreaders) (omit)
0.01 milliliter	10	(omit; too few)
Result	680	per milliliter.

5. When one of the duplicate plates comes within the prescribed limits and the other shows too many or too few colonies, both plates must be either included in or excluded from the average as follows, except as indicated under 4: (*a*) where the average of the two duplicate plates falls within the limits, both shall be included in the average and (*b*) when the average of the two falls outside the limits, both shall be excluded.

Examples

(*a*)

0.01 milliliter	422	(average 397, within limit, all plates included in average)
0.01 milliliter	372	
0.001 milliliter	39	
Result	395	

(*b*)

0.1 milliliter	255	
0.01 milliliter	26	(average 24, not within limit, both of duplicates excluded)
0.01 milliliter	22	

6. When more than one set of duplicate plates is made, equal authority should be given to each set, providing the number of colonies on the plates falls within the prescribed limits.

EXPLANATION OF SYMBOLS USED IN OBTAINING AND RECORDING BACTERIOLOGICAL RESULTS

For broth tubes—

0 Indicates no apparent growth.
— Indicates no gas production.
b Indicates small amount of gas which remains in spherical form at top of tube.
± Indicates an amount of gas greater than "b," but less than 10 percent.
+ Indicates an amount of gas varying from 10 to 49 percent.
# Indicates an amount of gas varying from 50 to 100 percent.

For confirmatory plates—

0 Indicates sterile plate, no growth.
— Indicates plate with nontypical.
± Indicates plate with questionable typical growth.
+ Indicates plate with typical colonies.

For designating quantities planted.—On record cards portions of sample examined shall be indicated by the decimal system as 10, 1.0, 0.1, 0.01, 0.001, 0.0001, etc., milliliter. On plates or tubes, where there is a possibility of accidental erasure

of some of the figures in handling, the 0.001-milliliter portion should be marked 2; the 0.0001, 3; the 0.00001, 4; etc. This system can be easily remembered by noting that the numerals 2, 3, 4, etc., represent the number of ciphers between the decimal point and the unit figure.

Most probable numbers per ml. of sample, planting 3 portions in each of 3 dilutions in geometric series

[L=Largest portion. M=Middle portion. S=Smallest portion]

Number of positive tubes L M S	3-10 3- 1 3- .1	3-1 3- .1 3- .01	3-.1 3-.01 3-.001	3-.01 3-.001 3-.0001	Number of positive tubes L M S	3-10 3- 1 3- .1	3-1 3- .1 3- .01	3-.1 3-.01 3-.001	3-.01 3-.001 3-.0001
0 0 0	-----	-----	-----	-----	2 0 0	.091	.91	9.1	91
0 0 1	.03	.3	3	30	2 0 1	.14	1.4	14	140
0 0 2	.06	.6	6	60	2 0 2	.20	2.0	20	200
0 0 3	.09	.9	9	90	2 0 3	.26	2.6	26	260
0 1 0	.03	.3	3	30	2 1 0	.15	1.5	15	150
0 1 1	.061	.61	6.1	61	2 1 1	.20	2.0	20	200
0 1 2	.092	.92	9.2	92	2 1 2	.27	2.7	27	270
0 1 3	.12	1.2	12	120	2 1 3	.34	3.4	34	340
0 2 0	.062	.62	6.2	62	2 2 0	.21	2.1	21	210
0 2 1	.093	.93	9.3	93	2 2 1	.28	2.8	28	280
0 2 2	.12	1.2	12	120	2 2 2	.35	3.5	35	350
0 2 3	.16	1.6	16	160	2 2 3	.42	4.2	42	420
0 3 0	.094	.94	9.4	94	2 3 0	.29	2.9	29	290
0 3 1	.13	1.3	13	130	2 3 1	.36	3.6	36	360
0 3 2	.16	1.6	16	160	2 3 2	.44	4.4	44	440
0 3 3	.19	1.9	19	190	2 3 3	.53	5.3	53	530
1 0 0	.036	.36	3.6	36	3 0 0	.23	2.3	23	230
1 0 1	.072	.72	7.2	72	3 0 1	.39	3.9	39	390
1 0 2	.11	1.1	11	110	3 0 2	.64	6.4	64	640
1 0 3	.15	1.5	15	150	3 0 3	.95	9.5	95	950
1 1 0	.073	.73	7.3	73	3 1 0	.43	4.3	43	430
1 1 1	.11	1.1	11	110	3 1 1	.75	7.5	75	750
1 1 2	.15	1.5	15	150	3 1 2	1.20	12.0	120	1,200
1 1 3	.19	1.9	19	190	3 1 3	1.60	16.0	160	1,600
1 2 0	.11	1.1	11	110	3 2 0	.93	9.3	93	930
1 2 1	.15	1.5	15	150	3 2 1	1.50	15.0	150	1,500
1 2 2	.20	2.0	20	200	3 2 2	2.10	21.0	210	2,100
1 2 3	.24	2.4	24	240	3 2 3	2.90	29.0	290	2,900
1 3 0	.16	1.6	16	160	3 3 0	2.40	24.0	240	2,400
1 3 1	.20	2.0	20	200	3 3 1	4.60	46.0	460	4,600
1 3 2	.24	2.4	24	240	3 3 2	11.00	110.0	1,100	11,000
1 3 3	.29	2.9	29	290	3 3 3	-----	-----	-----	-----

MEMORANDUM NO. 4 (JANUARY 6, 1939)

OUTLINE OF CHEMICAL METHODS

The routine chemical analysis to be made on water samples during the Ohio River Pollution survey will include the following determinations: Turbidity, alkalinity (and/or acidity, if indicated), total and volatile suspended solids, pH, nitrite nitrogen, dissolved oxygen, and 5-day biochemical oxygen demand. The dissolved oxygen shall be determined on individual samples collected at each point of every sampling section or station. Biochemical oxygen demand shall be determined on the total composite of the left, center, and right point samples at each sampling station. If a sample from only one point is collected at any sampling station, the biochemical oxygen demand must be determined on it.

Nitrite determinations are to be made to determine what method must be used in making the dissolved-oxygen determinations. If the dissolved-oxygen determinations are to be made in the field to the point of titration (at points most distant from the central laboratory) then the nitrite determination must

also be made in the field. In all samples where 0.05 part per million or more nitrite is found, a procedure for destroying nitrite must be used before dissolved oxygen is determined. If less than 0.05 part per million of nitrite is found, the unmodified Winkler method may be employed. If, after a period of daily nitrite examinations, it is found that most sampling points are likely to contain nitrite above 0.05 part per million at times, it will be best to adopt the corrective procedure in all cases and to eliminate the nitrite determinations.

Turbidity, alkalinity, total and volatile suspended solids and pH determinations will be made only on samples from special designated stations. The water samples for these determinations may be poured from the sampling can into a wide mouth 32-ounce bottle and transported to the laboratory. At stations where three points on a section of the river are being sampled, this bottle shall be poured about one-third full at each point from a measure, provided for the purpose, full of water taken from the sample collector by dipping. In all of these determinations the methods described in Standard Methods for the Analysis of Water and Sewage, eighth edition, will be used as far as possible. A brief description of these procedures, with detailed instructions in any cases of deviation from these methods, follows:

TURBIDITY

The square 32-ounce bottles containing the special samples may be compared with standards of silica suspensions prepared in the same kind of bottles for turbidities of 25 parts per million and less. The standard candle turbidimeter shall be used to determine turbidities of over 25 parts per million, the vanishing point taken as the depth of sample at which the image of the standard candle flame first becomes evenly diffused over the entire cross-section of the tube.

HYDRION CONCENTRATIONS (pH)

The pH determination shall be made electrometrically using the glass electrode. (A Leeds & Northrup Universal pH indicator will be supplied to the boat for this purpose and the L. & N. meter using the old, larger glass electrodes will be available at this station.) When the calomel and glass electrodes have been prepared and the meter has been assembled, the following precautions should be observed in making a pH reading. First, the vessel which is to contain the sample for measurement must be thoroughly cleaned. It should be rinsed once with distilled water and once with the sample to be examined before it is filled with sample. The temperature of the sample should be taken at this point and the temperature compensation dial on the meter adjusted properly. The dry cells or other source of electromotive force are then balanced against the standard cell of the meter by intermittently pressing the key marked "S. C." and adjusting the variable resistance until no deflection is obtained on the galvanometer. The pH of the sample may then be determined by intermittently pressing the key marked "pH" and adjusting the pH scale until the galvanometer shows no deflection. When no deflection of the galvanometer is obtained by pressing the pH key the scale reading indicates directly the pH of the sample. If the dry cells cannot be balanced against the standard cell, the dry cells are run down and must be replaced before a pH reading can be obtained. On any sample in which the pH is found to be 5.1 or less, a determination for acidity is indicated.[1]

ALKALINITY

The alkalinity should be determined on a portion of the special composite sample from the 32-ounce bottle. The standard method should be used, employing N/50 H_2SO_4 and methyl orange indicator.

TOTAL AND VOLATILE SUSPENDED SOLIDS

The suspended solids should be determined by filtering 50 to 100 milliliters of the special sample, with suction, through a Gooch crucible which has been prepared with an asbestos mat, dried, ignited, and weighed. After filtration the crucibles are dried at 103° to 105° C. for 2½ hours, cooled in a desiccator and weighed. The crucibles are to be ignited at 600° C. for 10 to 15 minutes in the

[1] At points in the upper stream where acidity determinations are necessary, this determination should be made by titration of hot and cold portions of sample with phenolphthalein and by titration of a cold portion using methyl red as an indicator. Methyl red with a color change at a pH of 5.1 should not be substituted for methyl orange in the alkalinity determination. Neither should methyl orange with a color change at pH 4.0 be substituted for methyl red in the acidity determination.

muffle furnace at the main laboratory and may be heated at dull red heat with a Meeker burner on the boat in determining the volatile suspended solids.

NITRITE NITROGEN

This test, employing the standard method, is to be carried out in the field or immediately after the samples arrive at the laboratory, but in any case before the dissolved-oxygen determination is started. For the field test, our sample collector should be provided with the reagents for making this test (sulfanilic acid solution and a-naphthylamine acetate solution), together with the necessary standard solution, two 500-milliliter bottles of distilled water, a number of pipettes and two 100-milliliter low-form Nessler tubes. All of this material, along with the reagents for making the dissolved-oxygen determinations will be carried in a special kit provided for that purpose. The nitrite test should be made on the composite sample at each sampling station as soon as the sample is collected. This test shall be directed to determine whether or not nitrite is present rather than to determine the exact amount present. Consequently, only one standard of 0.05 part per million will be required and it will be necessary only to determine whether or not the nitrite-nitrogen content is less than 0.05 part per million.

DISSOLVED OXYGEN

Because of the probability of encountering the various interfering substances in any investigation of the scope of Ohio River pollution survey, it is impossible to select one procedure for dissolved oxygen that will be applicable in all cases. Other interfering substances besides nitrite, such as ferrous and ferric salts, organic matter, and sulfite wastes, may be encountered in samples from some points and the chemist must be on the alert for evidences of these materials so that the best corrective procedure for any particular material may be applied. On all upper-river sampling points the chemist should make ferrous and total iron determinations before the method of determining dissolved oxygen is selected.

The following procedures are all applicable under certain circumstances. These are listed in the order of their simplicity and the special conditions under which they should or should not be applied:

(1) *Regular Winkler method.*—(See pp. 144–145, Standard Methods.) This method should be applied on samples from all points of the main stream which contain less than 0.05 part per million of nitrite, 1.0 part per million of ferrous iron, and 10 parts per million of total iron. On all of the lower-river points the iron content will probably be lower than the above limits so that the nitrite test will determine whether the regular Winkler method should be used.

(2) *Short Winkler method.*—This method should be applied to samples containing mud or sludge where the limits mentioned above for nitrite and iron are met, but where a large amount of interfering organic matter is present. Consequently, it will rarely be necessary to use this method on Ohio River samples.

(3) *The Alsterberg sodium azide procedure.*—This procedure should be applied on Ohio River samples where the iron content meets the limits stated under (1), but where more than 0.05 part per million of nitrite nitrogen is found. The detailed procedure for this method is given in the Analytical Edition of the Journal of Industrial and Engineering Chemistry (vol. 10, No. 12, p. 701 (1938)).

(4) *The Rideal Stewart modification.*—This procedure should be used on any Ohio River samples which contain appreciable (1.0 part per million or more) amounts of ferrous iron. As each part per million of ferrous iron would produce an apparent loss of 0.14 part per million of dissolved oxygen, one part is taken as the upper limit of tolerance for the ordinary Winkler or Alsterberg procedure. If more than 1.0 part per million is present this should be oxidized by the acid permanganate following the Rideal Stewart procedure (pp. 147–148, Standard Methods).

(5) *The alkaline hypochlorite modification.*—This method may be necessary at sampling points where considerable quantities of paper-mill wastes are encountered.

5-DAY BIOCHEMICAL OXYGEN DEMAND

The 5-day biochemical oxygen demand determination shall be made according to the standard method, except in the following details of procedure:

I. The phosphate buffered formula C water [2] shall be used wherever dilution of

[2] Theriault, E. J., McNamee, P. D., and Butterfield, C. T., Experimental Studies of Natural Purification in Polluted Waters. V. Selection of Dilution Water for Use in Oxygen Demand Tests. Public Health Reports 46, 1084–1116 (1931).

samples is required. The four solutions required to make up this dilution water are—

(A) Ferric chloride—0.27 gram $Fe\ Cl_3 \cdot 6\ H_2O$ per liter.
(B) Calcium chloride—18.3 grams $Ca\ Cl_2 \cdot 4\ H_2O$ per liter.
(C) Magnesium sulfate—9.9 grams $Mg\ SO_4 \cdot 7\ H_2O$ per liter.
(D) Phosphate buffer—34.04 grams KH_2PO_4 and 175 milliliters of N/1 NaOH per liter.

The following amounts of each of these solutions are added to distilled water, free of copper, to prepare the dilution water:

(A) 0.5 milliliter per liter or 8.0 milliliters per 16-liter carboy.
(B) 2.5 milliliters per liter or 40.0 milliliters per 16-liter carboy.
(C) 2.5 milliliters per liter or 40.0 milliliters per 16-liter carboy.
(D) 1.25 milliliters per liter or 20.0 milliliters per 16-liter carboy.

The bicarbonate dilution water of Standard Methods shall not be used.

II. The incubation bottles should be 250-milliliter capacity, with ground-glass stoppers, cleansed with concentrated sulfuric acid, carefully rinsed and dried before use. Water seals may be dispensed with except during the summer months when undiluted river water with an initial temperature higher than 20° C. is to be incubated. On any special biochemical-oxygen-demand work in which a series of bottles are incubated for long periods it is desirable to water seal the bottles during incubation.

III. On any sample in which the pH is found to be below 6.0 it will be necessary to adjust the pH to 7.0 to 7.2 with N/10 NaOH before incubation for biochemical oxygen demand. After the pH adjustment has been made, the sample should be reseeded with river water at a normal pH. About 20 milliliters of river water per liter of sample or about 5 milliliters for an individual dissolved oxygen bottle should be used for seeding.

IV. Where it is necessary to dilute the sample before incubation the dilution technique employed should not reaerate the diluted sample. This procedure is chosen in order that a calculated initial dissolved-oxygen content of the diluted sample may be made from the known dissolved-oxygen content of the sample and the dilution water, if it is desired. For this reason, the dissolved-oxygen content of the dilution water used with any sample must always be determined and recorded on the sample card. It will probably be found that 50-percent dilution will usually suffice on Ohio River samples that require dilution. In rare instances it may be necessary to make a 33⅓-percent or even a 25-percent dilution of the sample. When the dilution factor has been decided it should be recorded and the proper volume of sample should be siphoned into a 1-liter cylinder. Dilution water is then siphoned into the cylinder to the 1-liter graduation, being delivered below the surface of the liquid, and the dilution is thoroughly mixed without aeration with the special stirring device. After mixing, the sample is immediately siphoned into three properly labeled 250-milliliter biochemical-oxygen-demand bottles. If the diluted sample contains considerable settleable suspended matter, the stirring should be continued while the sample is being siphoned into bottles. The dissolved-oxygen content of one bottle is determined at once. The other bottles are incubated at 20° C. for 5 days and the final dissolved-oxygen content is then determined. If the amount of other work required makes it necessary, the check bottle, after incubation, may be eliminated. In making the dissolved-oxygen determinations for the biochemical-oxygen-demand test the sodium-azide modification of the Winkler procedure should be used when necessary, in order to eliminate interference due to nitrites that may be formed during incubation.

V. If the initial mean dissolved-oxygen content of the water at any sampling section is over 9.5 parts per million the oxygen content of the water shall be reduced before the sample is incubated for the biochemical-oxygen-demand determination. In such cases the water sample for the biochemical-oxygen-demand composite is poured into a bottle about twice the size necessary to hold it. The stoppered bottle is then carefully warmed in a water bath until the temperature of the sample reaches 20 to 30° C. The bottle is then vigorously shaken for several minutes to remove the excess oxygen. After shaking the sample is cooled to 20° C. and siphoned into 250-milliliter biochemical-oxygen-demand bottles. The initial dissolved-oxygen content is determined on one of these and the others are incubated at 20° C.

Memorandum No. 5 (January 12, 1939)

Instructions Concerning the Use of Bacto-Brilliant Green Lactose Bile Agar for the Enumeration of Organisms of the Coli-aerogenes Group of Bacteria

Comparative results on the enumeration of coli-aerogenes group bacteria in river water obtained, (1) by the standard procedure using lactose broth as a primary medium, with three duplicate tubes at each dilution in three or more decimal dilutions of a sample, and (2) by plate counts from the same samples using a differential plating medium, bacto-brilliant green lactose bile agar, have indicated a very high degree of correlation.

As results by the direct plating method are much easier to obtain and are not subject to the errors common to the dilution method, this procedure will be followed for the enumeration of members of the coli-aerogenes group of bacteria for samples from certain sampling points in the Ohio River pollution survey, either in addition to the determination as made by the standard procedure, or with the exclusion of the determination by the standard procedure. The sampling points from which samples will be examined for coli-aerogenes group bacteria by the direct plating method and instructions as to whether this method shall be used in addition to, or to the exclusion of the standard procedure, will be set forth in subsequent communications.

PROCEDURE TO BE FOLLOWED

In general the procedure for making plate counts after 24 hours incubation at 37° C., as given in standard methods and as interpreted in memorandum No. 3 (December 29, 1938), will be followed. Certain detailed items of technique, which apply to this direct plating procedure, will now be given.

PREPARATION OF MEDIUM

All media for this study will be prepared from dehydrated bacto-brilliant green lactose bile agar (serial No. 36793), in accordance with the instructions given (reference Noble & Tonney, Journal of the American Water Works Association 27:108:1935). Single strength medium, which is to be used for planting 2 milliliters or less portions, is prepared by dissolving with heat 20.6 grams of dehydrated powder in 1,000 milliliters of distilled water. Care must be exercised to prevent the powder burning on the bottom of the vessel before it is entirely dissolved. As soon as the powder is completely dissolved, mix thoroughly and distribute into agar bottles, putting 50 to 150 milliliters in each bottle, depending on the daily requirement of the particular laboratory. Cotton plug, paper cap, and mark the bottles as for standard agar. Sterilize at 15 pounds live-steam pressure for 15 minutes. (The time requirement of 20 minutes cited on the container presupposes the availablity of live steam from pressure lines. With our conditions, requiring a longer period for the development of 15 pounds of steam pressure when the steam is generated in the autoclave, a 15-minute interval, after the correct pressure has been reached, has been found sufficient). Medium, thus sterilized, will be stored in the refrigerator until required for use. This period of storage should not exceed 10 to 14 days as it will deteriorate after this period.

PLANTING

The general instructions referred to will be followed. Portions of samples (diluted if necessary), should be planted of such volume that the counts obtained for members of the coli-aerogenes group will be within the range of 25 to 400 colonies per plate. The ideal range of colonies per plate is from 50 to 150. As many pairs of duplicate plates as necessary, to obtain counts within the permissible limits, may be planted, but it should be possible after experience with the particular samples under investigation to limit this number to 2 pairs.

Sufficient agar at a temperature of 40 to 41° C. should be poured into the plates to provide for a uniform depth of agar of approximately 0.3 centimeter in the finished plate. This will require 15 to 20 milliliters of agar per plate depending on the diameter of the particular Petri dishes employed.

INCUBATION AND COUNTING

Plates, thus made, will be incubated at 37° C. for 16 to 18 hours before counting. They should be counted during the interval between 16 and 18 hours of incubation as prior to this period all colonies may not be characteristically visible and after this period extraneous colonies, whose appearance may be confusing, may appear. In counting the colonies, an illuminated counter provided with a white or silver-gray background should be employed.

As the bacterial content of a sample may change quite rapidly, the samples should be planted as soon as they arrive in the laboratory. Where comparative coli-aerogenes group enumerations are being made with the results obtained (1) by the direct-plating method and (2) by the standard lactose broth enrichment method, plantings should be made for both enumerations at the same time. These requirements, if the sample should arrive in the laboratory during the morning hours, say 10 a. m., would mean that the 16–18-hour period of incubation would be fulfilled at an inopportune time, namely at 2 to 4 a. m. of the following day. To provide for these difficulties and at the same time meet the incubation requirements, the brilliant green lactose bile agar plates may be placed in the refrigerator immediately after they are planted and solidified. At this stage the bacterial cells from the sample are held fixed in the agar and growth, as thought of in terms of 37° C. incubation, is stopped. Plates held thus in the refrigerator may be placed in the 37° C. incubator at 3 p. m. and the 18-hour incubation period will then be complete at 9 a. m. the next day. For plates that have been chilled in this manner in the refrigerator, approximately an 18-hour period of incubation should probably be allowed, rather than 16–18, as it will take approximately an hour for the cold plates to get to incubation temperature. Experience with counting and with the particular refrigerator available will indicate the proper time interval to the bacteriologist.

RECOGNITION AND IDENTIFICATION OF COLONIES

While colonies formed by members of the coli-aerogenes group of bacteria in this medium do have a characteristic morphology and a black to red color, familiarity with their appearance can be obtained more definitely with visual inspection and testing than by attempts at verbal description. This knowledge should be obtained in two ways: (1) By planting pure cultures of coli-aerogenes bacteria; in appropriate dilution, and observing carefully the appearance of the colonies; and (2) by picking colonies on plates made from natural samples for confirmation. To carry out this latter procedure, all of the colonies counted from a given area on a plate (10 is an appropriate number) should be picked to brilliant green bile lactose broth for partial confirmation. The production of gas in any amount in this broth, after 24 to 48 hours of incubation at 37° C., shall be accepted as evidence that the colony picked contained some member of the coli-aerogenes group of bacteria.

To insure fairness in the identification and to avoid the selection of particular types of colonies, an area should be circumscribed on the bottom of the plate enclosing about 10 colonies which have been counted and all of the colonies enclosed within this area which have been included in the coli-aerogenes count should be picked. This procedure should be followed with each sample and records kept of the results until the bacteriologist has established a high degree of accuracy, at least 90 percent, in the selection of the colonies counted.

RECORDING OF RESULTS

The rules given for the recording and averaging of results in memorandum No. 3 shall be applied to results obtained with this special medium.

Memorandum No. 8 (March 1939)

Collection and Examination of Biological Samples

In the following memorandum, detailed directions are given concerning the collection and biological examination of river water and bottom sediment samples. It is desirable, in this connection, to note here very briefly, the broad objectives of the biological examinations in a survey of the general character represented by the one now in progress in the Ohio River Basin.

These objectives may be stated as follows, having in mind the essentially practical nature of the present survey:

1. A study of the distribution of pollution and nonpollutional organisms in the river water and in the bottom sediments, both in the more highly polluted sections of the river and in those affected more remotely by pollution. In this connection, reference may be made to the results of previous observations in the Ohio and Illinois Rivers.

2. A survey of stream sections affected by certain types of industrial pollution, such as acid mine, tannery, paper pulp, soap, chemical and other similar wastes, with a view to estimating the extent to which these waters may interfere with the normal distribution and functions of organisms which are concerned in natural purification of the stream.

3. A special study of the occurrence of organisms in the river causing tastes and odors in water supplies, or interference with the economical purification of water supplies. This would include a consideration of pollution and other conditions in the river which might have a bearing on the prevalence of taste-producing or filter-clogging organisms.

The present survey differs very markedly from previous studies of the Ohio River in that it is not primarily a research project. It is concerned with locating seriouly polluted stretches of the Ohio and its tributaries and with obtaining the observational data necessary to estimating the nature and extent of corrective measures which will be required in each situation for restoring a stream to a reasonable degree of cleanliness, having in mind the more essential water uses of the particular stream. For this reason it is not proposed to undertake establishing any extensive array of new facts or principles bearing on the fundamental nature of stream pollution and purification phenomena, but rather to utilize those facts which are already known as the basis of evaluating the specific problems of stream pollution which now exist in the Ohio River and its tributaries. This general viewpoint may be said to be a guidepost for all of the laboratory studies connected with the present survey, including the biological studies.

A. PLANKTON SAMPLES

For the present, the regular bacteriological samples will serve as plankton samples also.

On arrival of these bacteriological samples at the laboratory, or at the laboratory boat *Kiski*, the biologist, if present, will arrange, with cooperation of the officer in charge, to secure a portion (about 100 cubic centimeters or more) of the sample.

If the biologist is located elsewhere temporarily (perhaps on field duty), the person in charge of the samples, or some person designated by the director of the laboratory, should procure the plankton samples from the bacteriological samples as follows:

1. Compositing of samples, if necessary,[3] should be done as soon as possible after arrival of the samples.

2. One hundred cubic centimeters or more of the composited water is to be dosed with 3 cubic centimeters of formalin, labeled stating station and date, and set aside for the biologist when he shall arrive.

3. In any case, 100 cubic centimeters is the minimum amount required for a plankton sample. If the biologist is present, he will centrifuge the 100 cubic centimeters sample at once, and will examine the unkilled catch. In case of 2 or more samples requiring attention at the same time, the unkilled 100-cubic-centimeter sample is to be placed in the ice box until it can be centrifuged.

B. BOTTOM SEDIMENTS (TO BE COLLECTED ONCE A MONTH AT SELECTED STATIONS)

Equipment required.—One small dredge, or a mushroom-shaped mud scoop, with 50- or 60-foot line attached, 1 small curved garden trowel or stout dipper, strips of tough white paper about 1 by 5 inches (for labels) and mason quart jars, one for each sample, with about 80 cubic centimeters of formalin in the jar.

Procedure.—

(1) Throw the scoop out, harpoon fashion, as far as possible from the boat. When the scoop has reached bottom drag it 5 or 6 feet to secure a bottom sample. Pull the scoop and contents aboard.

[3] Necessary only in case of right, center, and left samples.

(2) With trowel or dipper select portions of the mud in the scoop representative of the entire catch and drop these selections in the jar. (Guard against splashing formalin in your face.) Make the jar three-fourths full, or more.

(3) Using a soft lead pencil (do not use indelible), write the station, the location in channel (right, center, and left) and the date, and drop this label in the jar. Deliver the sample to the biologist, or to the man who transfers samples to the laboratory.

(4) If the sampler brings up pebbles, rubbish, fungus-like masses attached to stones or sticks, etc. include a fair proportion of these things in the jar sample.

(5) Bottom sediments are sometimes swept away by flood conditions. The first try may fail to get a bottom sample. Try another portion of the channel. Get the sample if possible. This is important.

(6) Discard mud remaining in sampler, rinse this, coil line, and have everything ready for taking the next sample.

C. EXAMINATION OF SAMPLES (PLANKTON)

1. *Concentration.*—Mix the sample thoroughly by gentle agitation. Place a measured amount, 100 cubic centimeters if possible, in centrifuge tubes, and centrifuge for 5 minutes at high speed (about 3,500 revolutions per minute). Pour off excess water and remove the catch (by catch is meant the concentrated contents of the entire sample) from the centrifuge tubes to a bottle or vial already provided with a label stating the station, the date, and the concentration of the catch. Get all of the catch from the tubes by rinsing with a half cubic centimeter of clean water, adding this rinsing to the catch already in the vial. The total amount of the catch is now measured, using, for convenience, a 10 cubic centimeter delivery pipette. If (*a*) the amount is, for example, 4½ cubic centimeters sufficient water should be added to eliminate the fraction, thus making 5 cubic centimeters. (*b*) If the amount be 8 or 9 cubic centimeters it is advisable to add enough water to bring the total volume up to 10 cubic centimeters. This data should be added to the label: "100 c. c. to 5 c. c." or "100 c. c. to 10 c. c." This statement of concentration means that by counting all the organisms in all of the catch, we thus ascertain the total content of the 100 cubic centimeters sample of water. Similarly, if we count the organisms in 1 cubic centimeter of the catch in (*a*) above, we thus ascertain the content of one-fifth of the original water, or 20 cubic centimeters.

2. *The count.*—The counting-cell method: The microscopical examination or counting is accomplished as follows, using the Sedgwick-Rafter counting cell, which holds 1 cubic centimeter and has a depth of exactly 1 millimeter:

(*a*) Thoroughly, but gently, mix the entire catch.

(*b*) Using a graduated pipette which does not have a fine tip (this may be broken or filed off) deliver 1 cubic centimeter of the mixed catch to the cell.

(*c*) Affix the glass cover by a sideways motion of this cover, as suggested by Whipple.[4]

(*d*) With a low-power microscope (about 20 or 30 diameter) examine the entire cell, moving it back and forth across the stage and inspecting every portion of the 20- by 50-millimeter area thus presented. This is a search for any relatively large organisms, such as crustacea, rotifers, small worms, and certain plant forms. Tabulate the number and kinds of these larger organisms, if any are present, in the "Survey" (or "Once-over") column of the plankton counting sheet. If catch (*a*) is used, this large organism count is really the content of 20 cubic centimeters of the original water. There may be a dozen organisms, or maybe only three or four, or perhaps none at all.

(*e*) The plankton counting sheet recommended by Whipple provides not only for this large organisms content but also for a representative count of the smallest organisms, which are usually very much more numerous than the large ones. For this small organism count, either 5 or 10 fields are selected in representative positions of this counting cell, and the organisms in these fields are counted under a higher magnification, usually 16-millimeter objective and 10× ocular. This ocular is provided with a Whipple ocular micrometer disk, and the tube length of the microscope is adjusted by use of a stage micrometer so that the largest square on the disk exactly subtends 1 square millimeter on the stage. This square millimeter is the "field" to be counted, and since the counting cell is exactly 1 millimeter in depth, we are counting, on the floor of the cell, the organisms that represent 1 cubic millimeter of the catch from the original plankton

[4] Microscopy of Drinking Water, Revision by Fair and Whipple, p. 96.

sample. Five fields therefore represent five one-thousandths or one two-hundredth of the contents of the counting cell, this cell being 20 by 50 millimeters and having an area of 1,000 square millimeters. Ten fields counted represent ten one-thousandths or one one-hundredth of the contents of the counting cell, and so on, whatever numbers of fields may be counted. If, for instance, we have in the 5 representative fields counted:

(1) 20 of organism A.
10 of organism B.
15 of organism C.

we know that these totals are only one two-hundredth of what are actually in the entire cell, so multiplying by 200 we have:

(2) 4,000 of organism A.
2,000 of organism B.
3,000 of organism C.

These largest numbers represent the actual total content of the counting cell.

Now, because this "catch" in the counting cell is a concentration, we must take this fact into consideration before we can state the result of our count in terms of the original sample of water. Since we concentrated the 100-cubic centimeter sample to 5 cubic centimeters (in the case of (*a*)) 1 cubic centimeter of the concentrated "catch" must therefore contain the organisms content of 20 cubic centimeters of the original water. In other words, the totals stated in (2) are 20 times as great as the actual content of the original water. To find this latter value, therefore, we divide these items by 20, with results as follows:

(3) 200 of organism A.
100 of organism B.
150 of organism C.

For convenience, a formula involving the preceding relative values is often used. It is as follows:

$$\frac{\text{Cubic millimeters in 1 cubic centimeter of the catch (in the cell)}}{\text{Cubic millimeters (fields) examined}} \times \frac{\text{Cubic centimeters of concentrated "catch" obtained}}{\text{Cubic centimeters of original sample of water used}} = \text{Factor}$$

Substituting values in the above formula:

$$\frac{1000}{5} \times \frac{5}{100} = \text{Factor } (=10)$$

This "factor" is the number by which we must multiply our five-field count data in order to express these values in terms of the actual content of the original water.

The cover-glass method: Lackey's method[5] of counting a definite portion of the catch by using several cover-slip mounts instead of the old-time counting cell has the unquestioned advantage of enabling the operator to switch instantly to the high power when the low power is found insufficient to identify the organism. Such occasions may be frequent, and the cover-glass method may be the preferable method, particularly if the large majority of the plankton organisms are very small. The large forms, however, should not be overlooked, although they are usually few in comparison in many cases—fewer than 1 per milliliter (or cubic centimeter). Quantitatively considered, however, these few large organisms may nearly equal, or possibly overbalance, the larger numbers of very small organisms. One Rotifer tardus equals approximately 10 Codonella, or 80 Halteria, in volume. An ideal procedure would seem to be a combination of (1) the cover-glass method, because of its great advantage of identification by use of the high power, with (2) a rapid count, or inspection, of a larger quantity of the plankton catch either in a 1-cubic centimeter counting cell or by inspecting, under low power, all of the area of at least 10 cover-slip mounts, which would be the equivalent of about one-half of the 1-cubic centimeter counting cell. This procedure would at once reveal the presence—or the absence—of the larger organisms and their relative abundance.

[5] Public Health Reports 53: No. 47, Nov. 25, 1938. Manipulation and Counting of River Plankton. By J. B. Lackey.

Lackey's cover-glass method[5] is essentially as follows:

1. The centrifuged catch is mixed, and measured in terms of drops by using a pipette, so that 1 drop of catch bears a definite relationship to the amount of sample centrifuged. For example, if a 100-milliliter sample, centrifuged, yields 76 drops of catch, enough of the decanted portion (in this case 24 drops) is added to make a total of 100 drops. This makes 1 drop of the catch equal 1 milliliter of the original sample.

2. To count, place 1 drop of the catch on the center of a slide and cover with a No. 1 25-millimeter cover-glass (preferably square).

3. Using the low-power objective, count two paths entirely across the spread-out drop, one path horizontal, the other vertical, the two paths crossing at or near the center of the drop.

4. Repeat (3) with several other drops, perhaps 10 or more, until the tota or combined width of the 20 or more paths counted (2 paths per drop) is equivalent, to the total diameter of the square cover-glass. In other words, the equivalent of 1 entire drop has been counted, and this completed count represents the organism content of 1 milliliter of water of the original sample. In an unkilled catch, some of the organisms will quickly migrate to the edge of the cover-glass, seeking oxygen. Others will die, becoming motionless and perhaps difficult to detect. Still others will migrate toward the lighted edge or portion of the drop. By counting only 2 paths, then repeating this with a fresh mount, and so on (see 4) the above difficulties are minimized or avoided. The low-power examination will not take into account some of the small but significant organisms. Hence the same procedure is followed with the high dry (10 or 12.5× oculars, 40–45× objective) combination, as with the low. However, 1 cover-glass comprises about 80 paths at a magnification of ca. 500 diameters, so only a few paths (6, 8, or 10) are counted instead of a whole drop. This makes it necessary to use a factor for estimating the numbers per milliliter but if the procedure is constant, this factor and any error it introduces will be a constant. Furthermore, the entire catch from 100 milliliters may usually be encompassed in 50 or even 25 drops.

5. The entire area of each drop may be quickly inspected with the low power in order to note the possible presence of any large organisms, such as worms, rotifers, and crustacea.[6] If present in 10 milliliters of the original water sample, they will usually show up in the examination of the entire area of such a number of one-drop cover-glass mounts of plankton catch as are required to represent 10 milliliters of the original water. Large organisms as Paramacium, Aeolosoma, or Rotifer may be counted by using 2× or 5× oculars with the 10× objective thus permitting a very quick examination of an entire drop.

D. BOTTOM SEDIMENTS

Pending acquisition of a suitable dredge by which quantitative areal samples of bottom mud may be secured, the old-time mushroom-shaped scoop, formerly used on the Potomac, the Ohio, and the Illinois Rivers, may be used to secure a qualitative sample. This sample will furnish valuable information as to the make-up and the apparent sanitary status of the stream bottom, and the population of this mud (usually worms, mollusks, insect larvae, and similar forms) will give further information along the same general lines.

The present plans call for one bottom sample per month from such locations as are thought to be representative. These locations will usually coincide with some of the plankton sampling stations, but may not be so numerous. Moreover, one point, instead of three (right, center, and left) will usually be sufficient. This one point, at a given station, should be one where mud is available. It frequently happens that soft bottom (sediment) is available at only one of the right, center and left positions.

Collection of sediments.—See B. Bottom sediments.

Laboratory procedure with the mud samples.—Equipment needed:

One 2-liter muglike dish, with stout handle (a 2-liter miner's cup is ideal. Also half of a double-boiler is convenient).

Two or three moist chambers, large size (about 10-inch diameter).

One 7-inch square of 25–30 mesh brass screen (or cloth) with corners well rounded off.

One pair deep-jar forceps.

[6] See Public Health Reports, November 18, 1938. Protozoan Plankton as Indicators of Pollution. J. B. Lackey.

Proceed as follows:

1. Partly fill a moist chamber with clean water.

2. On the outside of the mason jar containing the mud sample, mark, with grease pencil, the upper level of the mud.

3. Empty the sample or part of it from the jar into the 2-liter miner's cup or other container. Record color, pastiness, odor, presence of pebbles, etc.

4. Introduce a partial fold extending from one side of the square of brass cloth, about to the center (not beyond) of this square. Press this partial fold over and grasp the now dished screen with thumb and finger at this triangular area where there are now three thicknesses of the screen. Thoroughly wet this screen on both sides.

5. Run 100 cubic centimeters or more of tap water into the miner's cup or other vessel containing the mud sample. Agitate by a vigorous rotary motion and at once pour the suspension through the sieve or screen, which you are holding firmly with thumb and finger of the other hand.

6. Run more tap water into the container, agitate as before, and pour through sieve.

7. When some "screenings" have accumulated, invert the dished screen upon the surface of the clean water in the moist chamber, slosh screen gently up and down, washing the catch from the now underside. It is convenient, at this point, to reverse the "dished" condition of the screen.

8. Proceed as in 5, 6, and 7 above, until all of the mud sample has been washed through the screen. Pebbles, sand, etc., will not wash through and may be discarded after inspection by the biologist.

9. Run tap water into the jar to the grease-pencil mark. (See 2.) Measure this water. This is the amount of your mud sample. Record on your examination sheet this amount to the nearest multiple of 5, like 875 cubic centimeters, 760 cubic centimeters, 985 cubic centimeters, 800 cubic centimeters, etc.

10. Examine the catch in the moist chamber. Count or estimate the number of worms, mollusks, insect larvae, or other organisms. Note the presence of kinds of attached growths, such as fungi, algae, stalked ciliates, bryozoa, and the like. Inspect the catch for the presence of capsules, indicating the propagation of tubificid worms.

Note any unusual abundance of detritus of any kind, such as leaf fragments, straw or chaff, bits of paper, fecal pellets of worms or insects, molts of insects, fibers apparently from a paper mill, sawdust, etc.

If pebbles or sand are present in considerable amount, the relative proportion of such material should be noted. For instance, a sample measuring a total of 850 cubic centimeters may consist of about 200 cubic centimeters of pebbles, 150 cubic centimeters of sand, and only 500 cubic centimeters of actual mud. As a rule, these materials (pebbles and sand) need not be introduced into the moist chamber at all (see 8), but if present in considerable amount in the sample this approximate amount should be recorded.

11. The record:

(*a*) Location, date, and amount of sample.
(*b*) Color, condition, and odor.
(*c*) Predominance, or relative abundance of plant fragments, detritus, wastes, sand, pebbles, etc.
(*d*) Population:
Worms (tubificid, naid, etc.).
Mollusks (bivalves and univalves).
Insect larvae (chironomids, May flies, caddis flies, etc.).
Attached forms such as bryozoa, stentors, stalked ciliates, etc.
Attached plant forms (diatoms, fungi, algae).
Detached plant forms (algae, fungi, submerged plants of the higher types, etc.).

12. Final statement of population density should be in terms of 1 liter of sediment. For instance, if an 800 cubic centimeter sample yields 2,000 worms, this means 2,500 in 1 liter.

Supplement to Memorandum No. 8

POINTS TO BE COVERED IN A BIOLOGICAL SURVEY OF THE OHIO RIVER

1. Preliminary to the work, the map of the drainage area should be thoroughly studied. This will give an idea of the—

Rapidity of run-off, which materially affects water age, hence biological productivity.

Relative arable-land conditions, materially affecting silt content of the water.
Population density.
General centers of industrial waste and their nature, e. g., mining areas, etc.

2. A determination should be made of the possible examinations. Since this cannot be determined by preliminary work, the following recommendations are made:

A. Regular examination of plankton samples taken by collectors, and examined after centrifuging. Only those plankters should be counted which have been shown to be favorably or unfavorably affected by domestic sewage.

It is recommended that 100 milliliters of raw river water be taken from each composite sample, centrifuged 3 to 5 minutes at speeds between 2,000 and 3,000 revolutions per minute, the supernatant water decanted, and the catch measured, either as so many milliliters, or as so many drops, 1 milliliter or 1 drop of catch having a definite ratio to the 100-milliliter sample. If large plankters, as some of the larger Rotifera, are present in abundance, it is recommended that the catch be examined in a counting chamber, under a low-power binocular at 50 to 100 diameters. If such large organisms are few, it is recommended that an additional count be made by the drop method (previously published) and that the following species be counted:

POLLUTION FAVORING	CLEAN-WATER FAVORING
Eudorina elegans.	Chroomonas, all species
Chlamydobotrys gracilis	Chrysococcus, all species
Pandorina morum	Cryptomonas erosa
Euglena gracilis	Cryptomonas ovata
Euglena fusca	Cryptoglena pigra
Euglena oxyuris	Dinobryon, all species
Euglena viridis	Domatomonas cylindrica
Lepocinclis texta	Euglena mutabilis
Anthophysa vegetans	Euglena sciotiensis
Collodictyon triciliatum	Euglena spirogyra
Carchesium spp.	Mallomonas caudata
Chilodonella uncinatus	Rhodomonas lacustris
Colpidium campylum	Synura uvella
Colpidium colpoda	Actinobolus radians
Colpoda cucullus	Codonella cratera
Colpoda aspera	Cyclidium spp.
Epistylis spp.	Strobilidium humile
Glaucoma scintillans	Strombidium spp.
Glaucoma pyriformis	Tintinnidium fluviatile
Lionotus fasciola	Attheya zachariasi
Paramecium caudatum	Melosira granulata
Stentor polymorphus	Melosira varians
Vorticella spp.	Synedra biceps
	Actinastrum hantschii
	Ankistrodesmus falcatus

Other species occurring in large numbers should be counted if time allows, but may not be significant; Cyclotella, Chlamydomonas, and possibly other species may occur in enormous numbers but not be significant. Hence, with lack of time, they can easily be preserved and possibly counted at another time.

B. The above plankton examination should reveal the sanitary condition of the water. But it should be supplemented by using a plankton net catch, which will include the crustacea and insect larvae which are not attached, also give a more accurate count of the large Rotifera, Nematoda, Gastrotricha, colonial protozoa, and larger algae and desmids. This net catch should be made once weekly at the dams in the Ohio, but is not so important in the tributary streams. The catch should be preserved in 5-percent formalin, for eventual more careful examination.

C. Bottom dwelling forms: See laboratory procedure with the mud samples.

D. It is recommended that traps holding glass slides suspended vertically be placed in the river at Cincinnati and at the *Kiski* to determine the rate of accumulation of attaching organisms. These can be examined at varying intervals.

E. Special examinations should be made of the plankton content, and also the bottom dwelling forms in tributaries to determine—

(*a*) Contributions to main river.
(*b*) Effects of specific trade wastes on those tributaries, as distillery wastes on Lawrenceburg Creek.

F. Isolated studies at various points during the course of the survey, to determine the immediate effect of industrial wastes, as a local effect. This would involve a survey above, one immediately below, and one several miles (or hours flow) below the point at which the waste enters the stream.

3. A correlation of the important factors should be carefully sought as the survey progresses. For example, at times of low flow, the acid of the coal-mining areas may travel far down the Ohio, but we as yet know nothing of its effects on life in the stream. Or a rain on the Licking may increase the turbidity of the Ohio greatly, without becoming an important diluting factor. But its effect on the plankton is to sharply decrease it.

Memorandum No. 9 (June 7, 1939)

Instructions Governing the Preparation of Bacteriological Culture Media From Dehydrated Stock Powder

It has been observed that difficulties have been encountered from time to time in the preparation of culture media from dehydrated products. These difficulties have been of two kinds: (1) Due to insufficient heating or to the formation of lumps when the dehydrated powder is added, the powder is not uniformly distributed when the mixture is prepared for sterilization. (2) Due to overheating or heating for too long a period, the finished media contain a precipitate which may be confusing. The contributing sources of error are extremely hard to detect when the media being prepared contain a dye.

Various types of preparatory methods have been tried out in detail and a procedure has been developed which (1) can be carried out rapidly, (2) avoids the difficulties referred to, and (3) produces a satisfactory, clear medium.

The instructions which follow are for a 1-liter portion of standard nutrient agar. If larger amounts are to be prepared, the same instructions will apply, multiplying the amounts given by the number of liters desired. The same instructions shall be applied to other varieties of dehydrated media, altering the amount of dehydrated powder employed per liter in accordance with the instructions given on the container.

Procedure for dissolving and preparing dehydrated standard nutrient agar:

(1) Put 800 milliliters of distilled water in pot or flask and apply heat.

(2) Weigh out 23.0 grams of dehydrated Standard nutrient agar, place in a beaker casserole or other suitable container and add 50 milliliters of cold distilled water slowly. Mix well to a heavy paste, making sure that all of the powder is evenly wetted and free from lumps. When the water in (1) is boiling briskly, add an additional 150 milliliters of cold distilled water to this paste and mix to give a free-flowing mixture.

(3) Add this concentrated agar suspension (2) to the boiling distilled water (1), stirring briskly and keeping the mixture boiling over a free flame. If the mixture has been prepared properly and is free from lumps, adequate solution of the agar will be obtained with 2 minutes (not to exceed 5) of boiling.

(4) Make up any loss in volume caused by evaporation.

(5) Distribute in containers in desired quantities and sterilize by autoclaving.

In the preparation with the apparatus available for use it may be found that the amount of cold water required for successfully carrying out step (2) may be decreased and the amount of boiling water in step (1) proportionately increased. If so this may be done, for the smaller the volume of water used in (2) and the larger the amount in (1) the less the interference with the boiling temperature and the desired result will be obtained more quickly; providing always that a sufficient amount of cold water is used in (2) to obtain an evenly wetted, lump-free, free-flowing mixture.

Memorandum No. 11 (March 27, 1940)

Information for Trailer Laboratory Crew

I. General

Operation of the mobile laboratory units had indicated that numerous problems and difficulties may arise not ordinarily encountered in the case of fixed laboratories with more ideal working conditions. This brief memorandum has been prepared with the idea of guiding the personnel of the units with respect to their duties and responsibilities.

On the basis of the work done in 1939 and in view of the decrease in number of tests to be made per sample in 1940, an average daily examination of eight samples, 5 days per week, is contemplated. The length of the working day will necessarily vary in this type of field work. In another section of this memorandum the principal duties of each member of the party have been listed in the order of their importance and priority. By proper use of time and close cooperation by members of the unit, it is believed that the daily laboratory routine can be carried out in an 8-hour day from Monday to Friday, 4 hours on Saturday, and a few hours, as necessary, on Sunday to examine samples under incubation. Modification of the sampling schedule may be necessary if the work cannot be completed in a 48-hour week. Occasionally it may be necessary for one or all members of the party to work longer hours than indicated above. If at all possible, without hindering the work, an equal time off shall be allowed for the extra time worked. The time off shall be taken within 2 weeks of the date the extra duty was performed and shall not be cumulative so as to add to the annual leave of the individual.

Change of location of trailer headquarters should be avoided on Sundays. However, Saturday moves should be made if sampling in a given area is completed by Friday of any week. Saturday is to be considered as a full working day of 8 hours, according to the regulations of the United States Public Health Service.

The principal duties of the various members of the party are outlined below for the guidance of each member of the trailer personnel.

II. Duties of Personnel

Junior chemist.—

(1) Supervise and direct the work of sample collector and laboratory attendants.

(2) Program the work with the guidance and assistance of the engineers from the Stream Sanitation Office and the Stream Pollution Investigations Station.

(3) Supervise and help in preparations for moving.

(4) Supervise and help in making set-ups on new locations, making all contacts with local authorities personally, if at all possible.

(5) Arrange with local authorities for use of any of their equipment or facilities—water, power, distilled water, etc.

(6) Carry on analytical work with such assistance as laboratory attendant can give when he has carried out his primary duties as outlined below.

(7) Complete laboratory records on analytical results, with help of laboratory attendant, within 1 week of completion of work at a given set-up, and send cards and general report covering the work to Cincinnati headquarters.

(8) Inform the Cincinnati office of all matters connected with pay-roll information and per diem, annual, or sick leave of any member of party, time of leaving and arriving at various places with trailer, etc.

(9) Send in on the last day of each month a tabulation showing—

(*a*) Number of samples collected (each regular collection at a sample point represents four samples—one is the bacteriological sample, one is the composite sample, and each dissolved oxygen bottle is a sample); four in all.
(*b*) Number of bacteriological examinations for *B. coli.*
(*c*) Number of bacteriological examinations for total count.
(*d*) Number of dissolved oxygen analyses made.
(*e*) Number of biochemical oxygen demand analyses made.
(*f*) Number of turbidity determinations made.
(*g*) Number of pH determinations made.
(*h*) Number of alkalinity determinations made.
(*i*) Number of hardness determinations made.
(*j*) Number of Fe tests made.
(*k*) Number of acidity determinations made.
(*l*) Number of nitrite determinations made.
(*m*) Number of any special determinations made.

Chauffeur.—

(1) Drive tow car and trailer unit from place to place and connect and disconnect tow car, etc., with help of other members of the party.
(2) Sample collections.
(3) Care of car and trailer, washing, greasing, and servicing, etc.
(4) Help in making set-ups on new locations.
(5) Call at post office for mail and express.
(6) Ship cases, etc.
(7) Help in dishwashing and laboratory work as instructed by junior chemist to complete working day after all the above duties have been carried out.

Laboratory attendant.—

(1) Prepare and sterilize media.
(2) Wash and sterilize glassware.
(3) Prepare laboratory reagents.
(4) Help preparing for moving trailer and in making set-ups on new locations.
(5) Assist junior chemist in analytical work, as directed, when above duties have been completed.
(6) Assist junior chemist in completing records on the laboratory cards.

III. PROPOSED SCHEDULE OF LABORATORY WORK

The routine tests contemplated are—

(1) Temperature.
(2) Dissolved oxygen—Azide method.
(3) Five-day biochemical oxygen demand.
(4) Coliform index—Dilution method.

The following determinations shall be made occasionally as explained below:

(1) Alkalinity.
(2) Turbidity.
(3) Hardness (soap method).
(4) Iron (total, ferrous, ferric).
(5) Acidity to phenolphthalein (hot and cold).
(6) pH.

Alkalinity shall be run on at least one sample from each sampling station. Turbidity and hardness shall be run on all samples at one station on each stream (preferably lowest point downstream). Iron, acidity, and pH tests shall be made only on stream samples where acid-mine drainage or other acid discharges result in pH values below 4.0, or where iron-bearing wastes are present in appreciable amounts.

Methods to be followed in making these determinations shall be in accordance with memorandum No. 4 on Outline of Chemical Methods, and any supplemental instructions on specific procedures issued from the Cincinnati station. Where there is any doubt as to tests not covered in these references, the procedures in Standard Methods shall be used.

IV. DETAILED INSTRUCTIONS

The actual time of reporting to work and leaving, lunch hour, etc., will vary with the duties of the individual. The sample collector will start his trips so as to be back with samples by 1 p. m. If it appears desirable, the junior chemist and laboratory attendant may stagger their shifts. This arrangement indicated certain advantages during the work carried on in 1939.

Tow car shall be garaged at the trailer location (usually a water plant) if not located too far from the living quarters of sample collector so as to be within reasonable walking distance. If there are no facilities available at the water plant for car storage, or if too far from town, the tow car shall be garaged at a public garage and voucher obtained by the chauffeur for this expense. The tow car shall be used only for official purposes. The Government shall not provide transportation for any member of the party between his living quarters and the trailer location. When trailer headquarters are changed, the chauffeur and laboratory attendant will use the tow car for their transportation. The junior chemist will have travel authority allowing use of his car or of Government transportation requests to take care of his transportation.

It may be necessary and desirable at times for the junior chemist to make field trips to sampling points to carry on dissolved oxygen tests, etc., in order to

properly locate certain sampling points. Whenever possible these trips shall be made either with the assistant public health engineer assigned to the trailers or in the Government tow car. If either of these two methods of transportation are not available he shall use his private car and report the mileage traveled and all necessary information on the regular voucher form provided for this purpose. A statement explaining the necessity for the trip and work done shall accompany this voucher in order that travel orders can be prepared covering the particular travel or trip involved.

Purchases may be made for any reasonable item, and emergency repairs can be taken care of in the field. Vouchers for such expenditures should be obtained. If possible, Government purchase orders shall be used for such expenditures.

The success of the mobile laboratories depends upon cooperation of all members and a good morale. These instructions are offered as a mechanical basis from which to work, but the success of the program depends upon each of the party members themselves.

Memorandum No. 12 (May 6, 1940)

SUPPLEMENTAL CHEMICAL PROCEDURES FOR UPPER OHIO RIVER SAMPLES

In the upper Ohio River and its tributaries acid-iron-bearing water will very likely be encountered. For this reason the following chemical tests and special procedures shall be followed to supplement and/or replace the procedures used in the middle Ohio River.

pH

The pH should be determined first either electrometrically or colorimetrically with an S. D. C. kit upon all samples. If the pH is 6.0 or above, total iron and one biochemical oxygen demand determination upon the water as received, without pH adjustment or seeding, should be made. But, if the pH of the sample is below 6.0, both total and ferrous iron and two biochemical oxygen demand determinations should be made. These biochemical oxygen demand determinations should be made as follows:

I. Upon one portion of the sample as received without pH adjustment or seeding.

II. Upon another portion following pH adjustment to 7.2 with N/10 sodium hydroxide and seeding with about 2.0 percent of normal river water (pH 6.8 to 8.0). The details of this procedure follow later.

ACIDITY

If the pH is below 6.0, the acidity to phenolpthalein of both hot and cold samples should be determined. When the pH is below 5.1 the phenolpthalein acidities and the acidity to methyl red should be determined. (See Standard Methods.)

IRON

Total iron may be determined by boiling 50 milliliters of sample with 5 milliliters of 6 N nitric acid for 5 minutes, adding 3 drops of permanganate solution and cooling. Add 5 milliliters of thiocyanate and compare immediately with standards prepared from standard iron solution with 6 N nitric acid (Standard Methods, p. 75). If the sample gives evidence of considerable pollution (is septic) the evaporation and ignition procedure of Standard Methods should be resorted to (item 2.1, p. 74).

FERROUS IRON

Ferrous iron should be determined when the pH of the sample is less than 6.0 by the procedure given on page 76 of Standard Methods. As one part of ferrous iron results in an oxygen loss of 0.14 parts per million in a neutral water and ferric iron increases the apparent oxygen content during the final acidification by the Winkler procedure, it is necessary to take the proper precautionary measures in determining dissolved oxygen in iron-bearing waters.

DISSOLVED OXYGEN

Because of the possibility of iron in the upper Ohio River and tributary water and the interference noted above, the Rideal Stewart procedure employing the introduction of 2 milliliters of 40 percent of $KF. 2H_2O$ following the sulfuric acid

and previous to the permanganate solution should be used for all dissolved oxygen determinations from new sources on the upper Ohio River system. If later experience upon water from any location consistently shows that samples have a pH above 6.0, are not septic and contain less than 10 parts per million of total iron (under these conditions ferrous iron should not be present) the sodium azide modification for dissolved oxygen may be employed. However, it should be noted that the production of a faint straw-yellow color during the preliminary treatment with acid azide indicates the presence of considerable ferric iron. About 40 parts per million of ferric iron can be detected by a faint color in a dissolved oxygen bottle. Larger quantities of iron increase the color intensity. Consequently the appearance of a straw or brown color during acid azide treatment indicates that the method is not applicable and that the use of potassium fluoride with the Rideal Stewart procedure should be followed. In carrying out the Rideal Stewart method the following important details of procedure must be carefully followed if dependable dissolved oxygen data are to be obtained. Follow the procedure outlined in Standard Methods item 2.1, page 147. Add 2 milliliters of potassium fluoride and continue exactly through item 2.4. After the addition of the potassium oxalate the samples must be allowed to decolorize in the dark. The procedure should not be completed as soon as decolorization is apparently complete, but the samples should be allowed to stand for an additional 30 minutes in the dark before the manganous sulfate and alkaline potassium iodide are added. After shaking and settling twice, samples are ready to be acidified and titrated. If for any reason the samples cannot be titrated immediately, they should be allowed to stand in the alkaline state until they can be titrated. Then they should be acidified, one at a time, using 2 milliliters of concentrated sulfuric acid in place of the phosphoric acid suggested in Standard Methods, and titrated immediately.

BIOCHEMICAL OXYGEN DEMAND, PROCEDURE II

The following biochemical oxygen demand procedure is to be applied as a supplementary test to the regular procedure where the pH of the sample is below 6.0. While a biochemical oxygen demand will be obtained in the pH range below 6.0, it is not due to the normal microflora and fauna. It is therefore necessary to make a pH adjustment to the normal biochemical range and reseed to obtain the normal biochemical oxygen demand. A portion of the sample should be carefully adjusted with N/10 NaOH until the pH is between 7.0 and 7.8 As this neutralization proceeds a heavy precipitate of ferric hydroxide may be obtained where much iron is present. When this occurs it is best to allow the precipitate to settle and check the pH on the supernatant. An attempt should be made to bring the pH to 7.2 but as long as pH 7.8 is not exceeded it is not necessary to readjust the pH with acid. After the pH has been adjusted, the sample should be seeded with 2.0 percent normal river water. If normal river water is not available, one milliliter of domestic sewage filtered through paper (Whatman No. 1) should be added per liter of sample. In either case the same concentration of seed used on the sample shall be put into dilution water and its biochemical oxygen demand determined so that a correction for seed can be made in the final biochemical oxygen demand calculations. In all cases where seeding is necessary, the biochemical oxygen demand obtained on the seed should be reported. The sample for biochemical oxygen demand should not be diluted until experience at the sampling point indicates that the dissolved oxygen will be depleted without dilution. In all cases where this supplemental biochemical oxygen demand after pH adjustment is made, the Rideal Stewart procedure employing potassium fluoride as described shall be used for all dissolved oxygen determinations.

APPENDIX II

SPECIFICATIONS FOR MOBILE LABORATORY UNIT

1. Service Requirements

The trailer specified herein is for use by the United States Public Health Service as a mobile laboratory unit. It will be moved from place to place by the tractor unit which will be furnished by the Government and delivered f. o. b. the railroad station nearest the contractor's delivery point. The tractor unit shall be unloaded and serviced by the contractor, who shall make any alterations necessary for installation of towing irons on the tractor unit. The cost of unloading, servicing, and alterations, if any, shall be included in the bid price. Installation of helper springs on the tractor unit shall be done by the trailer contractor.

The trailer and its tractor unit will travel to various parts of the United States over all kinds of roads and under various weather conditions which will necessitate unusually sturdy construction. Provision shall be made for adequate lighting, ventilation, plumbing, etc., as set forth in these specifications. Both plans and specifications form an integral part of the contract. Details described under specifications are equally binding as if shown on the plans and vice versa.

2. General Description

The unit shall be of the trailer type with a single rear axle equipped with single tires. The trailer shall be fully enclosed and provided with one side door near the front of the right side wall. Windows and door shall be installed as explained elsewhere in these specifications.

The trailer shall have the following minimum dimensions:

Inside length exclusive of nose section shall be not less than 15 feet.
Inside width exclusive of nose section shall be not less than 74 inches.
Inside height exclusive of nose section shall be not less than 78 inches.
Outside length over all, not less than 17 feet 2 inches.
Outside width over all, not less than 78 inches.
Outside height over all, not less than 99 inches.

Bidders must state the exact dimensions of the trailer they propose to furnish.

The center line of the axle shall be so located as to provide a load space length along the floor of not less than 7 feet 6 inches between the front edge of the front wheel housing and the front of the trailer at its widest width. Vertical load on drawbar for the trailer shell shall not exceed 300 pounds.

3. Frame and Bracing

The trailer shall be equipped with an all-steel chassis running the entire length of the under structure, with secure anchorage at points of spring attachment and side-wall attachment. The side-wall structure shall be securely attached and braced to the underbody so that the outside sheeting material when applied will form a rigid shell. All side-wall structural members shall be securely fastened together by cadmium-plated bolts or screws, to prevent rusting.

4. Floor, Walls, and Roof

The floor shall be made of double 5-ply floor paneling having a total thickness of 1 inch, and shall be covered by a good grade of linoleum at least one-eighth inch in thickness.

The outside walls from the lower rub rail to the roof rail shall be sheathed with three-sixteenths-inch ply metal. This material shall consist of a sheet of rust-proofed steel glued with a suitable waterproofed bond to plywood built up in similar fashion.

The curved roof bows shall be made of thoroughly seasoned spruce or equal placed close enough together and braced longitudinally so as to form a rigid roof construction. The roof bows shall be covered with 3-ply fir or equal plywood not less than three-sixteenths inch in thickness, painted with an asphaltic paint and then covered with No. 10 extra-heavy waterproof canvas, treated with aluminum paint, suitable for outside exposure.

The interior side walls and ceilings shall be covered with 3-ply fir or equal plywood not less than three-sixteenths inch in thickness and of kiln-dried, low-moisture-content stock. Space between inside and outside linings of roof and side walls shall be insulated against heat by a combination of not less than 1½ inches of dead air space filled with approved insulation, such as spun glass or equal. Floor and wheel housing shall be insulated with celotex and padding.

5. Axles, Wheels, and Tires

The axle shall be of a suitable alloy steel forged in one piece and equipped with the necessary hubs for the installation of wheel equipment. The axle capacity shall be ample to carry the load of trailer shell and a pay load of 2,000 pounds. The unit shall be equipped with suitable 12-leaf springs constructed of a high grade of silicon manganese steel. The wheels shall be constructed of pressed steel of the closed disk type, with chrome-plated hubs, and the outward appearance of same shall be in close conformity with the exterior appearance of the trailer unit. The tires furnished shall be of the proper size to accommodate the total weight of the trailer and equipment (pay load, 2,000 pounds) and shall be rated in accordance with the latest tire and rim association standards.

Spare tire, tube, and rim or wheel shall be provided and suitably mounted at the rear of the trailer unit. The tire carrier shall be equipped with a suitable locking device, complete with two keys. Tools for making a tire change shall be furnished.

6. Windows, Doors, and Ventilators

The trailer shall have eight windows located as shown on the plans, and of the sizes indicated there. The windows shall be of the drop type and all glass in the trailer shall be shatterproof glass. The trailer door shall have a window as shown on plans. A folding screen door shall be installed at the trailer doorway. Screen door, all drop windows, and ventilator opening shall be provided with removable 16-mesh copper screens. Each window shall be provided with a good grade roll shade of color to harmonize with the trailer color.

Roof ventilator opening shall be located as shown on plans with hinged hatch that may be opened to desired height from inside the trailer. An electric ventilating fan, with capacity of 200 cubic feet of air per minute, shall be provided and installed preferably in the roof ventilator space. Roof ventilator shall be built above the outer roof level if necessary to accommodate the fan. The fan unit shall not extend into the trailer below the inside ceiling surface. The fan shall operate satisfactorily on either 110-volt, 60-cycle, single-phase alternating current or on 110-volt direct current. A switch to control the fan operation shall be provided.

7. Brakes

The trailer shall be equipped with Warner electric brakes, or equal, having heavy-duty brake linings, and with a Warner brake control kit, or equal. The brakes shall be installed with all accessories and attachments, complete and ready for use. An adequate safety brake shall be furnished for locking the trailer wheels in case of emergency and for parking.

8. Electrical

(*a*) *Lights—6-volt system.*—The trailer shall be equipped with outside running lights to conform with Interstate Commerce Regulations and, in addition, equipped with combination "turn" signal and stop and tail lights. All of these lights and a central dome light in the trailer shall be connected to the tractor car through a convenient connector and operate with the tractor car light switch.

(*b*) *Wiring and general (110-volt electrical current; may be either direct or alternating).*—All wiring, electrical work and fixtures shall meet the requirements of the National Electrical Code.

Opening on the outside of the trailer, flush with the finished surface, there shall be installed a weather and dust proof electrical receptacle through which the trailer shall be supplied with electrical current from an outside source. The 110-volt electrical current shall be supplied to the trailer from an outside source by plugging

in the 150-foot electrical cable specified elsewhere. The outside receptacle shall be wired to a "Nofuze load center" located in the interior of the trailer at a convenient and accessible point. It shall also be located within 1 or 2 feet of the outside receptacle.

The load center shall be of the type made by either Graybar Electric Co. or Westinghouse Co.; the most compact unit available shall be selected. This load center shall have four single-pole circuits. Three shall be of 15-ampere capacity each, and the fourth of 20-ampere capacity. The 15-ampere circuits shall be wired to the following units:

(1) Seven 110-volt ceiling and wall lights, and ventilating fan.
(2) The two double wall receptacles on one side of the trailer.
(3) The two double wall receptacles on opposite side of trailer.

The 20-ampere circuit shall be wired to a double base receptacle located at the base of the trailer near the door, as shown on the drawings.

Four double electrical wall receptacles shall be installed as shown on drawings.

Interior lighting shall be provided by seven light fixtures located as indicated on the drawings. These fixtures shall be firmly fastened to the trailer shell and shall be of a type with bulb setting in a horizontal position and having an adjustable cylindrical shade or reflector with bronze finish on the exterior and aluminum-paint finish on the interior reflecting surface. Each fixture shall be an individual pull-chain switch, and all seven shall be controlled by a single switch located at the side of the trailer door.

The contractor shall furnish 150 feet of stranded electrical cord insulated with heavy live rubber, weatherproofed, with plugs and attachments, which shall carry the current from an outside source to the receptacle at the trailer. This cord or cable shall be of ample capacity to supply safely the current required to operate the present and future load which will be a total of 4,500 watts.

The attachment plug on one end of the cable shall fit into the receptacle provided in the front end of the trailer. The other end of the cable shall be fitted with a substantial two-pronged plug (with parallel prongs) for tapping into a standard 110-volt wall receptacle.

The dome light, shown on drawing (with independent switch at side of door), taillights and side clearance lights shall operate on 6-volt direct-current from tractor car-power system. Wiring and connections shall be installed independently of the 110-volt system. An outside receptacle shall be installed at the front end of the trailer for connection of the 6-volt trailer circuit to the tow-car circuit. A connecting cable shall be supplied for use with a standard Ford, Chevrolet, or Plymouth coupe as tractor car, and the trailer system shall be controlled by the tractor car light switch.

9. Water Supply

At the rear end of the trailer under rear sink, a 30-gallon water-storage tank shall be installed as indicated on the plans. The tank shall be made of rust-resistant materials and shall have two baffle plates built into it to minimize water motion and swaying. The tank shall have an outside spout for filling, and a drain plug in the bottom for draining it, accessible from the outside.

In addition to the tank-water supply, provision shall be made at the rear of the trailer for a three-fourths-inch hose connection to city pressure. On the outside this hose receptacle shall be equipped with a chrome-plated cap attached to the trailer with a chain. From the inside, a copper-tubing connection shall be made to a goose neck spigot. This fixture shall be installed at the sink at rear of the trailer. The piping, gooseneck spigot, and hose receptacle shall be provided and installed by the trailer contractor. This system shall be designed to operate without leaks or trouble at a pressure of 150 pounds per square inch.

All copper tubing used for water supply lines to faucets and tanks shall be housed and protected by wooden framing wherever they pass through cupboards or lockers.

10. Interior Furniture and Equipment

(a) *Front and rear lockers.*—Rear cove locker and front-end closet and lockers shall be built in as indicated on the plans. These units shall be made of plywood and shelves shall be installed as indicated.

A 5½-inch shelf with cleat one-fourth inch thick, and rising one-half inch above top of shelf level on ends and front edge, shall be installed as shown on plans.

(b) *Laboratory benches.*—The laboratory benches indicated on plans shall be built into the trailer. Drawers, cupboards, and open spaces beneath bench tops

shall be provided as shown on plans. All drawers and cupboard doors shall have adequate fasteners installed so they will remain shut during movement of trailer without the necessity of locking them. This furniture may be constructed of plywood of suitable thickness except the bench tops. These shall be made of 1-inch clear Douglas fir or equal, and shall have dowelled and glued joints so as to prevent opening of cracks. The bench tops shall be left unpainted, but doors, drawers, etc., shall be stained a light-oak color, and varnished to match interior wall finish of trailer. (Bench tops will be treated with acid-proof paint by the United States Public Health Service after delivery of trailers.) There shall be at least 36 inches clearance from under surface of bench tops to the floor. If possible, so as not to extend benches above window sill, this clearance shall be 38 inches.

The doors of the cupboard over the wheel housing shall have a clear opening 8 by 10 inches in size. This opening shall be covered by a 4-mesh brass screen neatly fastened to the doors from the inside. An opening 5 by 10 inches in size shall be provided in the wheel housing in this cupboard as shown on the drawings. This opening shall be screened with an 8-mesh brass screen. A hinged cover with a latch shall be placed over this opening inside the cupboard. The opening is to be used for providing ventilation to the 20° incubator compressor unit which is to be installed in this cupboard.

(*c*) *Ice box unit.*—Over the wheel housing opposite the door, an ice box and sink unit of standard trailer design shall be installed; plans indicate exact location. This unit shall have a 12- by 18-inch porcelain sink with drain and stop. A double-action water pump shall be installed at this sink with copper suction line to water-storage tank at rear of trailer.

The ice box shall be provided with an ice compartment having a capacity of not less than 40 pounds of ice. The food compartment shall have one shelf at midheight of the storage space. An outside drain from the ice compartment shall be provided. Ice and food compartment shall be made of rust-resistant materials.

(*d*) *Rear bench, sink, and covering.*—In the bench at the rear of the trailer a sink and lead covering on bench shall be installed. The sink shall be located as indicated on the plans and shall be similar and equal to that made by Kewaunee Manufacturing Co., Adrian, Mich., and shown on page 35 of their 1935 catalog, as sink No. S–755. This is a Karcite sink with dimensions as follow:

	Length	Width	Depth
	Inches	*Inches*	*Inches*
Inside	22	14	6
Outside	24¼	16¼	7⅛

The top of the sink cabinet and adjoining bench, as indicated on plans, shall be covered with sheet lead consisting of tellurium lead weighing not less than 4 pounds to the square foot and shall be sloped to drain into the sink. All joints shall be burned with pure lead. This lead sheet shall extend over the curb and into the sink opening. A raised bead shall be formed one-fourth inch high around all four edges of the sink bench and drainboard, to prevent spilled acids from dripping onto the floor. This bench top shall have a drip groove in the under side of the top at the outer edges and around sink opening to prevent capillary attraction carrying water into the case work. No solder shall be used in making any of the joints. Sink drain shall be of extra heavy tellurium lead, and all joints shall be burned with pure lead. No solder shall be used. The sink drain shall discharge to the ground and be convenient of access for connection of a hose when necessary or desirable to lead sink drainage to a sewer. A double action suction pump shall be installed at the rear sink, as shown on plans, with connection to the under side of water tank for delivering water to the sink. As noted under "Water supply" this sink shall also have a gooseneck spigot fixture to be supplied by city water pressure.

11. Miscellaneous

Trailer contractor shall supply a two-burner gasoline stove. This shall be a Coleman two-burner stove No. 392, or equal.

The trailer contractor shall supply two 1-quart size Pyrene fire extinguishers, or equal, with necessary wall clamps.

A trailer jack shall be provided by trailer contractor with a caster wheel, raising and lowering on a worm thread acting as a jack, to raise or lower front end of the trailer.

A pair of heavy-duty passenger-car type tire chains of the proper size for the trailer tires shall be furnished by the trailer contractor.

The trailer contractor shall furnish four stabilizing jacks of ample strength to steady the trailer unit against movement when it is set up for laboratory use. The following jacks, or equal, will be acceptable: E-3 Jack Twins, manufactured by Wiedman Specialty Co., 20 Clinton Street, Tonawanda, N. Y.

Drawbar, coupler, and tow iron.—Trailer contractor shall install drawbar equipment, firmly anchored to trailer underbody, as part of trailer contract. This drawbar shall be fitted with a ball and socket type of coupler, which shall be of ample strength to transfer trailer load to tractor unit. Safety chain shall also be supplied to augment this drawbar coupling.

A vent opening with vent pipe, flashing, and hood, installed, shall be provided. The vent shall not extend into the interior of the trailer but shall be capped temporarily. This vent unit is to be provided for future use as a stove vent. It shall be installed in the position indicated on the plans.

12. Tractor Unit

The tractor unit shall be a new coupe automobile furnished by the Government and delivered to the trailer contractor's plant. The trailer contractor shall make any necessary alterations to accommodate the trailer coupling device, the cost of alterations to be included in his bid price. The trailer-car contractor shall make all necessary electrical, brake, and drawbar connections. The tractor unit shall be equipped by the trailer-car contractor with the necessary iron bar by which the trailer shall be drawn. This bar shall be attached rigidly to at least two cross-frame members of the tow-car frame. It shall be of ample strength to support safely a drawbar load of 600 pounds. Helper springs shall be installed on the tractor car by the trailer contractor and shall adequately reinforce the rear springs of the tractor car for the load to be carried.

It shall be permissible for the trailer contractor to drive the tractor car under its own power provided—

(1) The helper springs, iron tow bar, etc., cannot be installed at the contractor's plant; and

(2) That the total distance traveled for having such installations made shall not exceed 50 miles.

13. Units to Be Supplied by Contractor

Trailer contractor shall furnish trailer built to conform to these specifications and shall include all furniture such as cabinets, cupboards, drawers, ice box and sink unit, capped vent opening for stove, water tank and necessary piping for both sink faucets, electrical wiring and receptacles, Nofuze load center, 150 feet of electrical connecting cable, a two-burner gasoline stove, two 1-quart fire extinguishers, ventilating fan, tire chains, and trailer jacks, all as specified.

14. Units to Be Supplied by United States Public Health Service

(To be installed by United States Public Health Service after delivery of trailer)

One autoclave.
One 20° C. incubator.
One 37° C. incubator.
One hot air sterilizer.
One electric hot plate.

15. Color and Lettering

The exterior finish shall be high-grade, automotive gray enamel. Exterior shall be painted gray and shall receive one primer coat, two color coats, and one finishing coat. Within 1 week of award of the contract, the successful bidder shall provide a sample color plate of the finished trailer color to the Government in order that it may be forwarded to the tractor-car contractor for the purpose of matching the colors of the two units.

The words:

Federal Security Agency
U. S. Public Health Service
Official

shall be placed in gold-leaf letters with black outlines on each side of the trailer. They shall be placed on the door of the trailer on one side and directly opposite on the other. The words "Federal Security Agency" shall be in letters ⅞ inch high; the words "U. S. Public Health Service" shall be in letters 1¼ inch high, and the word "Official" shall be in letters ⅝ inch high. All lettering shall be painted over with two coats of durable outside spar varnish.

16. Inspection and Delivery

After all the connections have been made to the tractor unit, a representative of the Government will inspect the trailers, tractor cars, and connections. At that time, if everything is satisfactory, the entire train shall be turned over to this inspector or shipped on Government bill of lading to the United States Public Health Service, Cincinnati, Ohio.

Due to the urgency of obtaining these units the bidder shall state the time in which delivery can be made. This delivery time will be duly considered in making the award of contract.

APPENDIX III

LABORATORY FORMS

CONTENTS

BENCH FORMS

COMPILATION FORMS

FINAL SUMMARY FORMS

Form No. 1

Form 9425
Revised September 1939

FEDERAL SECURITY AGENCY
PUBLIC HEALTH SERVICE

STREAM POLLUTION INVESTIGATIONS

BACTERIOLOGICAL DATA

From Section ______________ of ______________________________ at ______________________________ Sample No. ______________
Date collected ______________________________ hr. ____________ Date examined ______________________________ hr. ____________

Physical and Chemical Data	Total Colonies per Ml. Growing On				Coliform Determination	
	Amt. Ml.	Agar, 20° C., 48 Hr.	Amt. Ml.	Agar, 37° C., 24 Hr.	Amt. Ml.	Agar, Special
Temperature ______ °C.						
Turbidity ______ p. p. m.						
pH ______						
Chlorine ______ p. p. m.	Average ______		Average ______		Average ______	

COLIFORM GROUP DETERMINATIONS

Amt. in Ml.	Presumpt.		Partially Confirmed				Completed							Differentiation				
	Lactose Broth A		B. G. B. 2% Broth		E. M. B. Plate A		Lactose Broth B		E. M. B. Plate B		Agar Slant 24-48 Hr.			Broths, 96 Hr. 37° C.				
	Gas		Gas		Appearance		Gas		Appearance		At 37° C.				D. P. P.		Koser	Tryp.
	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	24 hr.	48 hr.	Gram	Pure	Spore		M. R.	V. P.	Cit.	Ind.

+ Result ____________ − ____________ − ____________ = ________________________ M. P. N. per ____________ Ml.

Form No. 2

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Oxygen demand at 20° C.

Source of sample ____

____________________________________ Date ________________, 19____

Sample	Days Incubated	Percent Concentration	Burette Reading, ml.		Dissolved Oxygen, p. p. m.				Oxygen Demand
			Initial	Final	Initial	Final	Depletion		
							Actual	Cor.	

Form 9437—Federal Security Agency—Public Health Service—Oct. 1939.

Form No. 3

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Chemical data

Laboratory ____________________________ Date ________________, 19____

Sample No.	Source or Station No.	pH	Turbidity	Alkalinity determination on 100 ml. Portion		Dissolved Oxygen	
				Burette Reading	Alka., p. p. m.	Method Used	Burette Readings, ml.

Form No. 4

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Acid stream water oxygen demand at 20° C.

Source of Sample --

Sample No. ------------------------ Date ---------------------------

Sample Incubated as Collected

Ferrous Iron	Initial	Final	Loss During Incubation
Sample ml.			
Standard Matched			
Titre, p. p. m.			

B. O. D. (D. O. method used -----------)

Days Incubated	Percent Concentration	Burette Reading, ml.		Dissolved Oxygen, p. p. m.				Oxygen Demand
		Initial	Final	Initial	Final	Depletion		
						Actual	Cor.	

Sample Incubated after pH adjustment and innoculation -------------------

Initial pH --------- pH after adjustment --------- Seed used ----------

Days Incubated	Percent Concentration	Burette Reading, ml.		Dissolved Oxygen, p. p. m.				Oxygen Demand
		Initial	Final	Initial	Final	Depletion		
						Actual	Cor.	

Form No. 5

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Acid stream water chemical data

Laboratory ________________________ Date ____________________________
Source ____________________________ Sample No. ______________________
pH __________________ Turbidity _____________ Color ________________

ALKALINITY			HARDNESS		
Sample ml.	Bur. Reading	P. P. M.	Sample ml.	Bur. Reading	P. P. M.

ACIDITY

Method	Sample ml.	Burette Readings	P. P. M.
Methyl Red			
Phenolphthalein, Hot			
Phenolphthalein, Cold			

TOTAL IRON

Sample ml.	Standard Matched or Burette Readings	P. P. M. Iron

Form No. 6

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Acid mine water chemical data

Sample__________________________ Source__________________________
pH________________________ Sulphate________________________ p. p. m.

ALKALINITY

Method	Sample, ml.	Readings	Alkalinity, p. p. m. as $CaCO_3$
Methyl Red__________	__________	__________	__________
Methyl Orange__________	__________	__________	__________

ACIDITY

Method	Sample, ml.	Burette Readings	Acidity, p. p. m. as $CaCO_3$	Electrometric pH at "E. P."
Methyl Red__________	__________	__________	__________	__________
Phenolphthalein Hot__________	__________	__________	__________	__________
Phenolphthalein Cold__________	__________	__________	__________	__________

TOTAL IRON

Sample, ml.	Standard Matched or Burette Reading	p. p. m. Iron
__________	__________	__________
__________	__________	__________
__________	__________	__________

(1) R_2O_3____________________p. p. m.

(2) $Al_2O_3 = R_2O_3 - 1.43\ Fe =$____________________p. p. m.
(3) $Al = 0.529 \times (2) =$____________________p. p. m.

Form No. 7

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Biological examination

Watershed________________ Mileage________________
Subwatershed________________ Mileage________________

Station	1	2	3	4	5	6	7	8	9	10	11	12
Location												
Mileage												
Date												
Agar Count												
Biochemical oxygen demand												
Dissolved oxygen												
pH												
PLANKTON (No. per ml.):												
ALGAE:												
Chrysophyceae:												
Chromulina sp												
Chrysococcus rufescens												
" major												
" ovalis												
" asper												
Mallomonas caudata												
" sp												
Hymenomonas roseola												
Synura uvella												
Dinobryon sertularia												
Lagynion Scherffelii												
Total												
Chryptophyceae:												
Rhodomonas lacustris												
Chroomonas spp												
Cryptomonas erosa												
" ovata												
Total												
Euglenophyceae:												
Euglena viridis												
" pisciformis												
" sanguinea												
" variabilis												
" Ehrenbergii												
" acus												
" oxyuris												
" torta												
" tripteris												
" deses												
" polymorpha												
" gracilis												
Lepocinclis ovum												
" texta												
Phacus longicauda												
" anacoleus												
" pleuronectes												
" triqueter												
" pyrum												
Trachelomonas volvocina												
" crebea												
" hispida												
" urceolata												
Cryptoglena pigra												
Peranema sp												
Petalomonas mediocanellata												
" carinata												
Total												

Biological examination—Continued

Station	1	2	3	4	5	6	7	8	9	10	11	12
PLANKTON (No. per ml.)—Continued.												
Chlorophyceae:												
Mesostigma viride												
" grande												
Heteromastix angulata												
Chlamydomonas spp												
Chlorogonium sp												
Sphaerellopsis fluviatilis												
Thorakomonas sp												
Wislouchiella planctonica												
Lobomonas rostrata												
Coccomonas orbicularis												
Phacotus lenticularis												
Pteromonas aculeata												
" cruciata												
Polytoma uvella												
Gonium pectorale												
" sociale												
Pandorina morum												
Eudorina elegans												
Actinastrum sp												
Ankistrodesmus sp												
Botryococcus sp												
Closterium sp												
Coelastrum sp												
Cosmarium sp												
Crucigenia sp												
Dictyosphaerium sp												
Golenkinia sp												
Oocystis sp												
Pediastrum sp												
Kirchneriella sp												
Scenedesmus sp												
Sorastrum sp												
Staurastrum sp												
Total												
Bacillarieae												
Synedra acus												
" radians												
" biceps												
" ulna												
Cyclotella spp												
Navicula spp												
Asterionella formosa												
Melosira sp												
Gomphonema sp												
Nitzschia sp												
Total												
Myxophyceae												
Anabaena sp												
Chroococcus sp												
Merismopedia sp												
Microcystis sp												
Oscillatoria sp												
Total												
Dinophyceae												
Total												

Biological examination—Continued

Station	1	2	3	4	5	6	7	8	9	10	11	12
PLANKTON (No. per ml.)—Continued.												
PROTOZOA	----	----	----	----	----	----	----	----	----	----	----	----
Amoeba sp	----	----	----	----	----	----	----	----	----	----	----	----
Codomonas annulata	----	----	----	----	----	----	----	----	----	----	----	----
Oicomonas sp	----	----	----	----	----	----	----	----	----	----	----	----
Domatomonas cylindrica	----	----	----	----	----	----	----	----	----	----	----	----
Bodo sp	----	----	----	----	----	----	----	----	----	----	----	----
Cladomonas sp	----	----	----	----	----	----	----	----	----	----	----	----
Vorticella sp	----	----	----	----	----	----	----	----	----	----	----	----
Podophrya sp	----	----	----	----	----	----	----	----	----	----	----	----
Codonella cratera	----	----	----	----	----	----	----	----	----	----	----	----
Prorodon sp	----	----	----	----	----	----	----	----	----	----	----	----
Colpodium colpoda	----	----	----	----	----	----	----	----	----	----	----	----
Urotricha farcta	----	----	----	----	----	----	----	----	----	----	----	----
Tintinnidium fluviatile	----	----	----	----	----	----	----	----	----	----	----	----
Collodictyon triciliatum	----	----	----	----	----	----	----	----	----	----	----	----
Glaucoma scintillans	----	----	----	----	----	----	----	----	----	----	----	----
Lionotus sp	----	----	----	----	----	----	----	----	----	----	----	----
Cyclidium sp	----	----	----	----	----	----	----	----	----	----	----	----
Actinophrys sol	----	----	----	----	----	----	----	----	----	----	----	----
Strobilidium humile	----	----	----	----	----	----	----	----	----	----	----	----
Strombidium sp	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
Total	----	----	----	----	----	----	----	----	----	----	----	----
ROTIFIERS AND CRUSTACEANS	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----	----	----	----
Total	----	----	----	----	----	----	----	----	----	----	----	----

Form No. 8

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Routine analyses

Laboratory ---------- Month of ----------, 19---- Compiled by --------

Sample No.					
Stream					
Station					
Place					
Point					
Date					
Time sampled					
River stage, gage ht. (ft.)					
River disch. (thous. sec. ft.)					
Water temperature, °C.:					
Right					
Center					
Left					
Average					
Dissolved oxygen:					
Parts per million:					
Right					
Center					
Left					
Average					
Percent sat.:					
Right					
Center					
Left					
Average					
5-day B. O. D. comp. or ave.					
Coliform group, most probable No. per ml.:					
Right					
Center					
Left					
Average					
Chemical tests:					
pH					
Parts per million:					
Turbidity					
Alkalinity					
Acidity					
Hardness					
Iron					

Form No. 9

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Acid stream water analyses

Stream ....
Station .... Laboratory ....
Place .... Compiled by ....
Point ....

Sample No.						Average
No. of days samples						
River disch. (thousands of sec. ft.)						
pH						
Alkalinity (M. O.) p. p. m						
Acidity, as $CaCO_3$, p. p. m.:						
Phenolphthalein, Hot						
Phenolphthalein, Cold						
Methyl Red						
Total						
Iron ferrous (p. p. m.):						
Initial						
Final						
Loss during Incubation						
5-day B. O. D. (p. p. m.):						
Acid sample:						
Observed						
Oxygen equiv. of loss in ferrous iron						
Corrected b. o. d						
Neutral sample:						
Observed						
Notes						

Remarks: ....

Form No. 10

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

River mud analyses

Sample No					
Source					
River stage					
Date collected					
Date received					
Condition					
Odor					
Appearance					
Percent grit (by volume)					
Percent moisture					
Volatile matter, p. p. m. (dry basis)					
Organic nitrogen p. p. m. (dry basis)					
Oxygen consumed, p. p. m. (dry basis)					
Apparent immediate demand (p. p. m.) (dry basis)					
B. O. D., p. p. m. (dry basis):					
1 day					
3 days					
5 days					
7 days					
9 days					
Value of *K*					

RESULTS BELOW EXPRESSED AS ORGANIC NITROGEN, OXYGEN CONSUMED, 5-DAY B. O. D., PER P. P. M. OF VOLATILE MATTER

Organic nitrogen					
Oxygen consumed					
5-day B. O. D					

Remarks: ....

U. S. PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY — Form No. 11

Work summary—Average results

Laboratory ______________ Month of ______________ 19 ____ Compiled by ______________

Station	Days sampled	River stage, gage height in feet	River discharge, thousands of sec. ft.	Water temperature, °C.				Dissolved oxygen								5-day B.O.D., p. p. m.	Agar count, per ml., 24 hrs., 37° C.	Coli-aerogenes group		Chemical determinations					
								Parts per million				Percent saturation						Dilution method, m. p. n./ml.	Direct count, per ml.	pH	Results in p. p. m.				
				R.	C.	L.	Ave.	R.	C.	L.	Ave.	R.	C.	L.	Ave.						Nitrites	Turbidity	Alkalinity	Suspended solids	
																								Total	Vol.

UNITED STATES PUBLIC HEALTH SERVICE—OHIO RIVER POLLUTION SURVEY

Form No. 12

Work summary—Average acid stream results

Laboratory ------------------------------------ Month of -------------------- 19---- Compiled by ----------------------

Station	Days sampled	River discharge, thousands of second ft.	pH	Alkalinity to methyl orange as $CaCO_3$ (p. p. m.)	Acidity as $CaCO_3$ (p. p. m.)			Iron (p. p. m.)				5-day B. O. D. (p. p. m.)				
					Phenolphthalein		Methyl Red	Total	Ferrous			Acid sample			Neutralized sample	
					Hot	Cold			Initial	Final	Loss during inc.	Observed B. O. D.	Ox. equiv. of loss in ferrous iron	Corrected B. O. D.	Observed B. O. D.	Notes

Table ---- *Form No. 13*

Ohio River Pollution Survey Laboratory Data

Source of Data:
Trailer Laboratory ------------
Cincinnati Laboratory ------------
Laboratory Boat *Kiski* ------------

------------ Watershed

Summary of Individual results

Sampling point	Mileage from mouth	Date	Average discharge, cubic feet per second	Temperature ° C.	Dissolved oxygen		5-day biochemical oxygen demand, parts per million	Coliforms, most probable number per milliliter	pH	Turbidity, parts per million	Alkalinity, parts per million	Hardness, parts per million
					Parts per million	Percent saturation						

Table ---- Form No. 14

Ohio River Pollution Survey Laboratory Data

Source of Data:
Trailer Laboratory ------------
Cincinnati Laboratory ------------
Laboratory Boat *Kiski* ------------

------------ Watershed

Summary of averages

Sampling point	Mileage from mouth	Period	Number of samples	Average discharge, cubic feet per second	Temperature, ° C.	Dissolved oxygen parts per million	5-day biochemical oxygen demand, parts per million	Coliforms, most probable number per milliliter	pH	Turbidity, parts per million	Alkalinity, parts per million	Hardness, parts per million

Form No. 15

TABLE ----

Source of Data:
Trailer Laboratory ---------------
Cincinnati Laboratory ------------
Laboratory Boat *Kiski* -----------

OHIO RIVER POLLUTION SURVEY LABORATORY DATA

Summary of Acid Stream Results

----------- -- Watershed

Stream	Sampling point	Date	Number samples	pH	Acidity, parts per million			Iron, parts per million	
					Methyl red	Phenolphthalein		Ferrous	Total
						Hot	Cold		

SUPPLEMENT C

ACID MINE DRAINAGE STUDIES

90035—44—pt. 2, vol. 2——9

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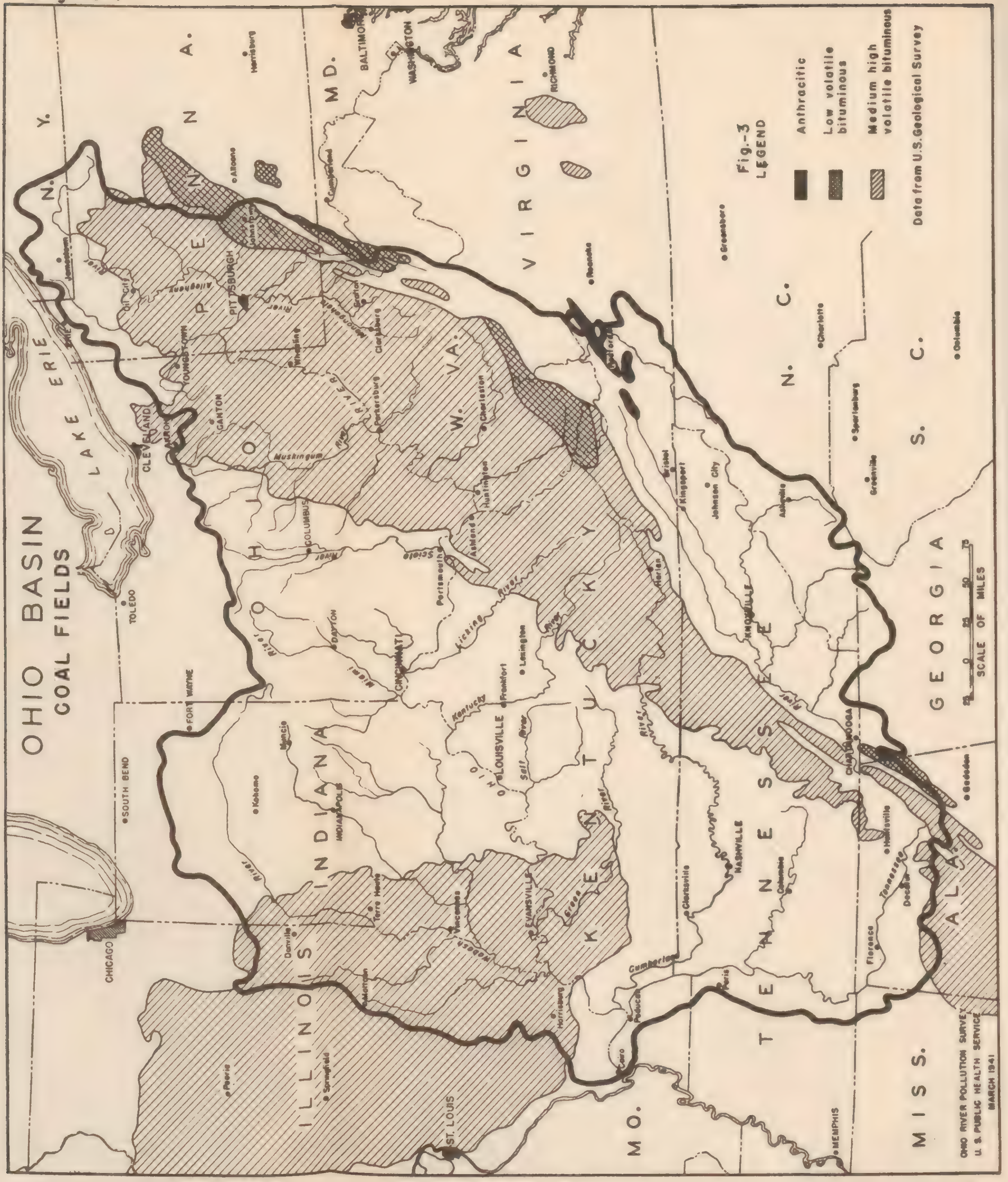
Fig. Ac-1


OHIO BASIN
COAL FIELDS
Fig.-3
LEGEND
Anthracitic
Low volatile bituminous
Medium high volatile bituminous
Data from U.S. Geological Survey
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
MARCH 1941
LAKE ERIE
N. Y.
PENNA.
MD.
VIRGINIA
W. VA.
OHIO
INDIANA
ILLINOIS
KENTUCKY
TENNESSEE
N. C.
S. C.
GEORGIA
ALA.
MISS.
MO.
PITTSBURGH
CLEVELAND
COLUMBUS
CINCINNATI
LOUISVILLE
INDIANAPOLIS
EVANSVILLE
NASHVILLE
KNOXVILLE
CHATTANOOGA
ST. LOUIS
CHICAGO
BALTIMORE
WASHINGTON
RICHMOND
TOLEDO
DAYTON
AKRON
CANTON
YOUNGSTOWN
FORT WAYNE
SOUTH BEND
MEMPHIS

ACID MINE DRAINAGE STUDIES

Introduction

Consideration of the acid mine drainage problem by the Ohio River Pollution Survey has been largely through the assembly and analysis of existing data. In this connection, the assistance of the Office of Mine Sealing, United States Public Health Service, is deserving of special mention. Records accumulated by that office, working with the Works Progress Administration over a period of 8 years, proved to be of great value.

Certain field studies were undertaken. A laboratory unit, stationed at Morgantown, W. Va., conducted a study of Deckers Creek during the latter half of 1940 and the first half of 1941. In addition, the effect of acid mine drainage is reflected in the results from the regular comprehensive stream-sampling program conducted throughout the Ohio River Basin.

A section of the Main Report of the Ohio River Pollution Survey has been devoted to the problem of acid mine drainage and that section with new table and figure numbers is included in this supplement as a summary and one of five general subdivisions into which this presentation is divided, as follows:

Summary for Main Report includes acid loads, costs and acid reduction by mine sealing, features of a mine acid control programs and summarized details of such a program for the upper Ohio River Basin.

General Features, including history and magnitude of the coal mining industry, types of mines, cause of acid formation, theory and practice of remedial measures, and legal features including State and Federal statutes and court decisions.

Presentation of Field Data including present acid load and its distribution in as much detail as the data warrant, the status of present remedial measures, the effects of acid mine drainage, and the type, extent and magnitude of damages caused.

Presentation of Laboratory Data making reference to the Morgantown, W. Va., and regular sampling results. Mention is made of stream quality trends over a period of years as indicated by water plant records.

Discussion, including presentation of a suggested comprehensive program to control acid pollution by further mine sealing and the use of flow regulation. Estimates of cost are included, together with financial justification for the program. The suggested program of acid pollution control is correlated with a parallel program of organic pollution control.

Summary for Main Report

Acid drainage from coal mines affects the streams throughout the area covered by the Ohio River Basin coal fields. (See fig. Ac-1.) In Pennsylvania and West Virginia, the two largest bituminous-coal-producing States, the problem dominates the stream sanitation picture. The present situation exists despite the fact that in these two States only 5.1 percent of the coal deposit has been mined out or lost. The present survey has conducted a study of the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Particular attention has been directed to control measures involving mine sealing and flow regulation, particularly by multiple-purpose use of flood-control and other purpose reservoirs. Studies and demonstrations by the United States Bureau of Mines of the possible accomplishments of mine sealing have shown that acid control at the mine is practical at reasonable cost, and a start, made in the form of a Works Progress Administration program (see fig. Ac-2) of sealing abandoned mines with United States Public Health Service and State cooperation, has confirmed (see fig. Ac-3) the earlier work. The present sealing program, however, is not a continuing activity having been discontinued from time to time in some States. Provision for essential maintenance is lacking. Flow regulation by flood-control reservoirs built by the United States Engineer Department has had a beneficial effect. Aggressive prosecution of a suggested remedial program is amply justified, particularly in the Pittsburgh district where tangible monetary benefits can be shown in excess of remedial costs. Remedial measures are imperative to insure the future of the principal streams in the mining areas.

ACID LOAD REDUCTION BY SEALING

Mine acid loads in the major tributaries of the Ohio River Basin as originally measured and after present sealing and suggested sealing under 1940 restrictions are given on figure Ac-2 and table Ac-1. Total basin acid loads from this table and the estimated load following a sealing program with 1940 restrictions modified are as follows:

	Tons per year
Original mine acid load	2,500,000
Reduction, to date, by sealing	700,000
Present mine acid load	1,800,000
Possible further reduction by sealing under 1940 restrictions	600,000
Load after sealing under 1940 restrictions	1,200,000
Possible further reduction with 1940 restrictions modified	600,000
Estimated ultimate residual load	600,000

Fig. Ac-2

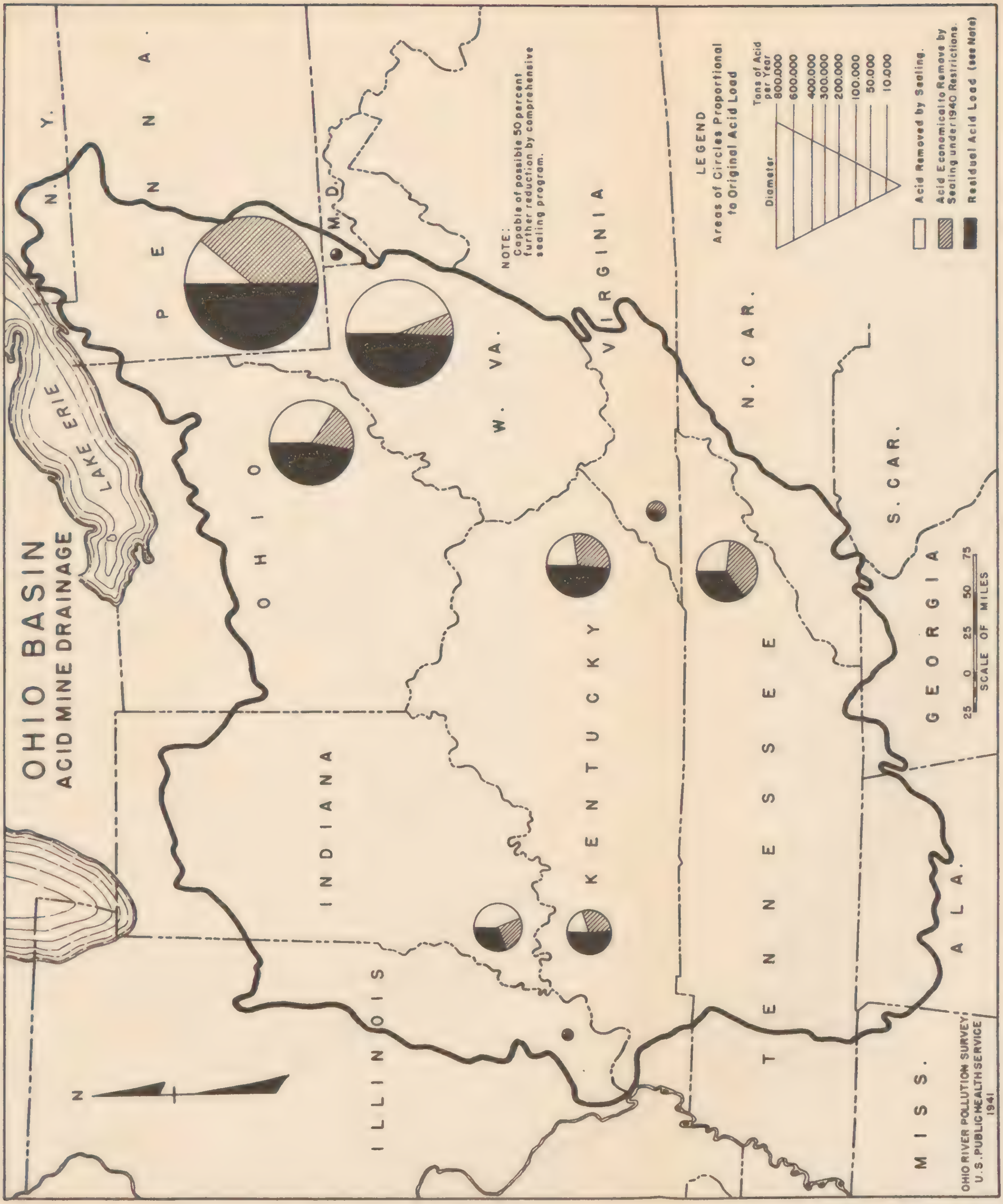

OHIO BASIN
ACID MINE DRAINAGE
LAKE ERIE
N. Y.
P E N N A.
M. D.
O H I O
W. VA.
V I R G I N I A
I N D I A N A
I L L I N O I S
K E N T U C K Y
T E N N E S S E E
N. CAR.
S. CAR.
G E O R G I A
A L A.
M I S S.
N
NOTE:
Capable of possible 50 percent further reduction by comprehensive sealing program.
LEGEND
Areas of Circles Proportional to Original Acid Load
Diameter
Tons of Acid per Year
800,000
600,000
400,000
300,000
200,000
100,000
50,000
10,000
Acid Removed by Sealing.
Acid Economical to Remove by Sealing under 1940 Restrictions.
Residual Acid Load (see Note)
25 0 25 50 75
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1941

Fig. Ac-3

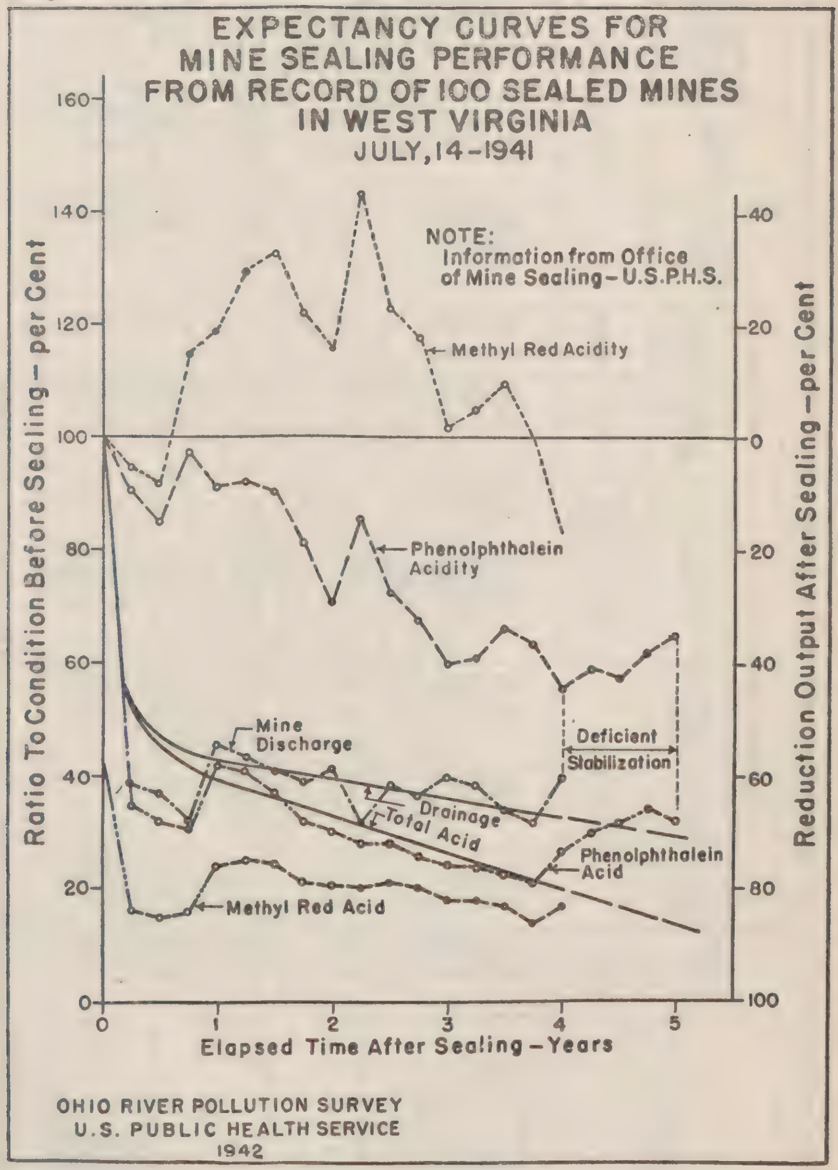

EXPECTANCY CURVES FOR
MINE SEALING PERFORMANCE
FROM RECORD OF 100 SEALED MINES
IN WEST VIRGINIA
JULY, 14-1941
NOTE:
Information from Office
of Mine Sealing - U.S.P.H.S.
Methyl Red Acidity
Phenolphthalein
Acidity
Mine
Discharge
Deficient
Stabilization
Drainage
Total Acid
Phenolphthalein
Acid
Methyl Red Acid
Ratio To Condition Before Sealing - per Cent
Reduction Output After Sealing - per Cent
Elapsed Time After Sealing - Years
0
20
40
60
80
100
120
140
160
1
2
3
4
5
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

TABLE AC–1.—*Acid mine drainage: Summary by tributary drainage basins and States of original classified mine-acid loads, intensity per square mile, acid removed by sealing, estimated acid economical to remove under 1940 restrictions, and residual mine-acid loads*

Tributary, drainage basin, and State	Drainage area	Original acid load as $CaCO_3$: Active mines	Original acid load as $CaCO_3$: Marginal mines [1]	Original acid load as $CaCO_3$: Abandoned mines	Original acid load as $CaCO_3$: Total mines	Original acid load as $CaCO_3$: Total mines	Sealed mines: Original acid load	Sealed mines: Efficiency	Acid removed by sealing	Present acid load	Economical to remove in addition by sealing	Residual acid load after sealing under 1940 restrictions [2]	Residual acid load after sealing under 1940 restrictions [2]
	Square miles	Tons per year	Tons per year	Tons per year	Tons per year	Tons per square mile per year	Tons per year	Percent	Tons per year	Tons per year	Tons per year	Tons per year	Percent
Minor tributary basins:													
Pennsylvania	1, 290	27, 380	11, 320	10, 697	49, 397	38. 3	14, 100	64	9, 030	40, 367	15, 050	25, 317	51
Ohio	6, 450	21, 100	7, 400	85, 000	113, 500	17. 6	45, 820	54	24, 750	88, 750	40, 200	48, 550	43
West Virginia	3, 005	7, 579	764	18, 464	26, 807	8. 9	14, 028	65	9, 120	17, 687	1, 770	15, 917	59
Kentucky	5, 680	4, 700	1, 300	11, 200	17, 200	3. 0	7, 854	50	3, 927	13, 273	4, 900	8, 373	49
Indiana	3, 480	2, 978	64	10, 013	13, 055	3. 8	6, 964	87	6, 060	6, 995	496	6, 499	50
Illinois	1, 645	356	1, 804	411	2, 571	1. 6	305	70	214	2, 357	1, 000	1, 357	53
Total	21, 550	64, 093	22, 652	135, 785	222, 530	10. 3	89, 071	60	53, 101	169, 429	63, 416	106, 013	48
Allegheny River except Kiskiminetas	9, 838	26, 457	6, 760	50, 244	83, 461	8. 5	24, 040	78	18, 750	64, 711	32, 330	32, 380	39
Kiskiminetas River	1, 892	223, 896	23, 805	73, 988	321, 689	170. 0	20, 270	54	10, 954	310, 735	132, 630	178, 105	55
Allegheny River, total	11, 730	250, 353	30, 565	124, 232	405, 150	34. 5	44, 310	67	29, 704	375, 446	164, 960	210, 486	52
Monongahela except Youghiogheny	5, 648	438, 274	39, 064	223, 634	700, 972	124. 1	380, 026	66	251, 900	449, 072	115, 630	333, 442	48
Youghiogheny River	1, 732	141, 735	25, 609	52, 340	219, 684	126. 8	29, 270	78	22, 742	196, 942	83, 050	113, 892	52
Monongahela River, total	7, 380	580, 009	64, 673	275, 974	920, 656	124. 7	409, 296	67	274, 642	646, 014	198, 680	447, 334	49
Beaver River	3, 145	5, 480	988	10, 920	17, 388	5. 5	5, 376	42	2, 280	15, 108	6, 500	8, 608	50
Muskingum and Hocking Rivers	9, 225	37, 700	14, 600	163, 500	215, 800	23. 4	170, 000	54	91, 400	124, 400	19, 000	105, 400	49
Little Kanawha River	2, 320	323	2	493	818	. 4	716	65	470	348	50	298	36
Kanawha River	12, 300	9, 210	995	22, 650	32, 855	2. 7	21, 157	65	13, 750	19, 105	2, 170	16, 935	52
Guyandot River	1, 670	15, 680	614	3, 890	20, 184	12. 1	14, 333	65	9, 320	10, 864	1, 330	9, 543	47
Big Sandy River	4, 280	16, 236	8, 997	35, 699	60, 932	14. 2	26, 324	56	14, 738	46, 194	18, 320	27, 874	46
Scioto River	6, 510	4, 900	2, 400	16, 800	24, 100	3. 7	11, 540	54	6, 230	17, 870	7, 100	10, 770	45
Little Miami River	1, 755	0	0	0	0	0						0	
Licking River	3, 670				Slight							0	

[1] Not completely abandoned.
[2] Areas connected to active ventilation systems and areas where costs exceed $10 per ton per year not included.

Miami River	5, 385	0	0	0	0	0						0	
Kentucky River	6, 940	10, 900	3, 200	27, 800	41, 900	6. 0	22, 865	50	11, 433	30, 467	9, 520	20, 947	50
Salt River	2, 890	0	0	0	0	0						0	
Green River	9, 220	26, 500	7, 900	42, 100	76, 500	8. 3	30, 230	50	15, 115	61, 385	23, 140	38, 245	50
Wabash River	33, 100	26, 777	3, 174	79, 631	109, 582	3. 3	54, 054	87	47, 040	62, 542	30, 403	32, 139	29
Saline River	1, 235				Slight							0	
Tradewater River	995	3, 000	1, 500	3, 400	7, 900	7. 9	1, 730	50	865	7, 035	3, 270	3, 765	48
Cumberland River	18, 000	53, 610	13, 045	198, 115	264, 770	14. 7	105, 056	65	68, 862	195, 908	93, 070	102, 838	39
Tennessee River	40, 600	4, 960	1, 145	32, 063	38, 168	. 9	20, 239	80	16, 200	21, 968	10, 770	11, 198	29
Unclassified, Virginia	7, 175				18, 750	2. 6	0		0	18, 750	11, 070	7, 680	41
Total	203, 900	1, 109, 731	176, 450	1, 173, 052	2, 477, 983	12. 2	1, 026, 288	64	655, 150	1, 822, 833	662, 769	1, 160, 064	47
Alabama	6, 810	0	0	0	0	0						0	
Georgia	1, 490	0	0	0	0	0						0	
Illinois	11, 440	356	1, 804	411	2, 571	0. 2	305	70	214	2, 357	1, 000	1, 357	53
Indiana	29, 135	29, 775	3, 238	89, 644	122, 637	4. 2	61, 018	87	53, 100	69, 537	30, 899	38, 638	32
Kentucky	39, 375	88, 900	31, 700	180, 000	300, 600	7. 6	129, 000	50	64, 500	236, 100	89, 500	146, 600	49
Maryland	430	535	79	847	1, 461	3. 4	570	60	342	1, 119	400	719	49
Mississippi	385	0	0	0	0	0						0	
New York	1, 955	0	0	0	0	0						0	
North Carolina	6, 260	0	0	0	0	0						0	
Ohio	29, 570	65, 000	25, 000	270, 000	360, 000	12. 2	229, 600	54	123, 590	236, 410	68, 900	167, 510	46
Pennsylvania	15, 620	521, 513	90, 003	277, 833	889, 349	56. 9	128, 237	72	91, 804	797, 545	349, 560	447, 985	50
Tennessee	33, 645	25, 170	5, 190	160, 478	190, 838	5. 7	74, 771	80	59, 800	131, 038	72, 440	58, 598	31
Virginia (unclassified)	7, 175				18, 750	2. 6	0		0	18, 750	11, 070	7, 680	41
West Virginia	20, 610	378, 502	19, 436	193, 839	591, 777	28. 7	402, 787	65	261, 800	329, 977	39, 000	290, 977	49
Total	203, 900	1, 109, 731	176, 450	1, 173, 052	2, 477, 983	12. 2	1, 026, 288	64	655, 150	1, 822, 833	662, 769	1, 160, 064	47

The sealing program under 1940 restrictions is based on a cost limitation of $10 per ton of acid per year and sealing only in areas not connected to active ventilation systems. Modified restrictions would permit sealing operations in worked-out sections of active mines.

The cost and benefit estimates, discussed later, apply to work necessary to complete a sealing program under 1940 restrictions and the report discusses this completion as a first objective.

Free mineral acid from waste pickle liquor is estimated at 3.4 percent (see table Ac–8) of the present total free and combined mine-acid load. Acid from hydrolized iron sulfates may be minor or as high as 10 times this quantity depending on the hydrolysis equilibrium.

TABLE Ac–2.—*Acid-mine drainage: Cost of Works Progress Administration program of mine sealing to date and estimated to complete restricted mine-sealing program, both State-wide and for the Ohio River Basin*

State	State-wide expenditures			Ohio Basin expenditures	
	Total to date [1]	Per ton per year of acid sealed	Estimated to complete program	Estimated total to date [1]	Estimated to complete program
	By States				
Illinois	$12,000	$7.26		(2)	
Indiana	273,000	4.48	$80,000	$270,000	$80,000
Kentucky	340,000	2.66	1,200,000	340,000	1,200,000
Maryland	221,000	8.25	50,000	10,000	
Ohio	1,935,000	8.40	400,000	1,940,000	400,000
Pennsylvania	2,666,000	11.50	4,000,000	1,490,000	3,100,000
Tennessee	109,000	2.46	420,000	110,000	420,000
Virginia	0		150,000	0	150,000
West Virginia	1,462,000	3.00	200,000	1,210,000	160,000
Total	7,018,000	5.80	6,500,000	5,370,000	5,510,000
				By basins	
Minor tributary basins				$650,000	$480,000
Allegheny				510,000	1,460,000
Monongahela				1,820,000	1,600,000
Beaver				60,000	50,000
Muskingum and Hocking				1,450,000	110,000
Kanawha				70,000	120,000
Guyandot				40,000	10,000
Big Sandy				70,000	240,000
Scioto				100,000	40,000
Kentucky				60,000	130,000
Green				80,000	310,000
Wabash				240,000	80,000
Cumberland				200,000	780,000
Tennessee				20,000	100,000
Total				5,370,000	5,510,000

(1) Rounded. (2) Less than 5,000.

MINE-SEALING COSTS

Mine-sealing costs to date in the Ohio River Basin, as shown in table Ac–2, have been about $5,400,000. To complete a sealing program under 1940 restrictions will cost an estimated additional $5,500,000. Annual charges of interest (3½ percent), amortization (0.7 percent based on 3½ percent interest and a 50-year life), inspection (2 percent) and maintenance (7 to 10 percent) are about 15 percent or

$1,635,000 on the total of these two sums of $10,900,000. This is about 4 mills per net ton of production and confirms an estimate of the Office of Mine Sealing, United States Public Health Service. These and other estimates of future mine-sealing costs are believed conservatively high as they are based primarily on past experience with Works Progress Administration programs with the dual purpose of providing relief and improving mine-acid conditions.

MINE-ACID-CONTROL PROGRAM

Present information indicates that correction, in large measure, of the mine-acid pollution problem is practical by a comprehensive control program involving the following measures:

(*a*) Provision for the inspection and maintenance of present air seals and a similar provision in connection with all future mine-sealing programs.

(*b*) Completion of the present limited (1940 restrictions) mine-sealing program.

(*c*) Provision of reservoir capacity, presumably in primarily flood-control reservoirs, for flow regulation for acid- and organic-pollution control.

(*d*) Inauguration of an aggressive program of mine sealing with present restrictions modified.

(*e*) Adaptation of the better mining methods to acid control.

(*f*) Extension of the established practice of refraining from discharging acid waters to streams previously uncontaminated.

(*g*) Clarification of the laws governing mine drainage to facilitate the corrective program.

UPPER OHIO BASIN

For illustrative purposes and to indicate cost to benefit relationships, special studies have been made in the upper Ohio River Basin area or the area above the Ohio-West Virginia-Pennsylvania State line. Estimates have been made of accomplishments, costs, and benefits resulting from application of the first three of these items, namely, mine sealing, maintenance, and flow regulation. Any study of reservoir development should include consideration of organic-pollution control and the program studied considers both organic and acid pollution.

Damages.—Damages capable of monetary evaluation caused by acid mine drainage include neutralization and softening costs to domestic and industrial water supplies and corrosion of steamboats, barges, power-plant condensers, and river and harbor structures. These damages in the area above the Ohio-West Virginia-Pennsylvania State line, totaling about $2,000,000 per year, are shown on table Ac–3. Equally important, but intangible or unevaluated, damages are to water supply due to manganese, to recreation through the destruction of normal aquatic life, to agricultural uses, to highway structures, to the mines themselves, and indeterminate but serious damages to the public health due to rapid fluctuations in quality as reported by water-plant operators. Mine acid is a deterrent to organic pollution abatement, as incentive for abatement measures is lacking if the result is a stream suitable only for disposal of mine waters.

Mine acid is not a safeguard to public water supplies as the rapid increase in flow during a freshet may bring sufficient alkalinity to neutralize the acidity and eliminate any germicidal effect there may be.

TABLE Ac-3.—*Acid mine drainage: Summary, as of 1940, of annual damages, capable of accurate estimation and caused by acid mine drainage above the Ohio–West Virginia-Pennsylvania State line*

	Total annual damages
Domestic water supplies	$364,000
Industrial water supplies	407,000
Steamboats and barges	1,143,000
Power plants	76,000
River and harbor structures	76,000
Floating plant (U. S. Engineer Department)	5,000
Total, 1940	2,071,000
Future estimate (based on estimated future quality but no increase in use):	
1950	2,630,000
1960	3,190,000

Mine sealing.—Data on mine-acid loads before and after various stages of sealing, similar to that given on table Ac-1 for the upper Ohio River Basin are as follows:

	Tons per year
Original mine-acid load	1,375,000
Reduction, to date, by sealing	313,000
Present mine-acid load	1,062,000
Possible further reduction by sealing under 1940 restrictions	379,000
Load after sealing under 1940 restrictions	683,000

The completion of a mine-sealing program in this area under 1940 restrictions will cost an estimated $3,250,000. Annual charges, including interest, amortization, inspection, and maintenance as already enumerated, are 15 percent or $488,000 on this expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000 per year, making a total of $870,000 per year. As shown on figure Ac-3 if these existing seals are not maintained, the benefits already realized may easily be lost making it necessary to repeat the expenditure.

Flow regulation.—The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity but there will still remain acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest-flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage. The estimated reservoirs selected for acid control are the largest that can be used without storing for periods greater than 1 year. Utilization of increased capacity beyond this point would be infrequent and the unit value would therefore be reduced. Reservoir capacities selected in the upper Ohio River Basin area under these conditions are as follows:

	Acre-feet
Allegheny Basin	210, 000
Monongahela Basin	370, 000
Total	580, 000

Organic pollution in the upper main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 cubic feet per second during the warm summer months (25° C. or 77° F. average monthly air temperature) and progressively lesser flows as temperatures decrease. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drought occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drought. A valuable partial organic pollution control would be available during a year such as 1930.

Storage required for organic pollution abatement is 430,000 acre-feet (except in 1930), while total storage selected for acid control is 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Benefits and costs.—Benefits of the combined program due to acid control are due to a reduction in the damages detailed on table Ac-3. Benefits to organic pollution control are due to a reduction in the cost of needed sewage and industrial waste treatment.

Reduction in maximum monthly acidities equitably assigned to the two items—mine sealing and flow regulation—of this program are as follows:

	Acidity, parts per million [1]	
	Allegheny, at Aspinwall	Monongahela, above McKeesport
Present monthly maximum	23	33
Reduction by sealing [2]	22	19
Reduction by reservoirs [3]	14	10
Resulting monthly maximum [3]		4

[1] To methyl red on Allegheny and methyl orange on Monongahela.
[2] Equitably assigned or average improvement if remedy applied constructed first or second. As a rule, projects applied first show increased benefits at expense of later projects.
[3] 13 parts per million minimum alkalinity.

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela, and upper Ohio River Basin due to the suggested mine-sealing and flow-regulation programs total \$1,133,000 per year. This estimate is believed conservative as it is based on 1940 damages instead of greater possible future damages and it does not include benefits to unevaluated and intangible items. Deducting the cost of sealing of \$870,000 per year from these benefits leaves \$263,000 per year that can be spent on reservoir construction for acid and hardness reduction.

In correcting sewage and organic industrial waste pollution without flow regulation, a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is \$300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional \$300,000.

While the flow regulation is designed primarily for acid pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a valuable aid in organic pollution control. The two flow-regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic pollution control. An examination of flow and acidity records indicates that acid control and organic pollution abatement can both be accomplished with the exception of 1 month (also excepting 1930) in 10 years, and this accomplishment has been taken as satisfactory.

Annual benefits to flow regulation include \$263,000 left after deducting mine-sealing costs from acid and hardness control benefits, plus \$300,000 for organic pollution control at Pittsburgh and \$300,000 for organic pollution control benefits at Cincinnati, making a total of \$863,000 per year. For a storage of 580,000 acre-feet, the annual benefits or the amount that can be economically spent per acre-foot per year is \$1.49.

A summary of the cost and benefit relation is as follows:

	Annual benefits and costs
Benefits, acid control	\$1,133,000.00
Cost, mine sealing to date and future	870,000.00
Balance, acid control for reservoirs	263,000.00
Benefits, organic pollution control:	
Pittsburgh	300,000.00
Cincinnati	300,000.00
Total available for reservoirs	863,000.00
Total per acre-foot	1.49

Reservoir benefits are, in large measure, due to equalizing and surge-reducing effects following mine sealing in order to develop full benefits from the sealing program. The balance for reservoirs indicated is, therefore, available to the extent shown only if and when the mine-sealing program is assured. Mine sealing, on the other hand, can be justified beyond reasonable doubt as a single independent remedial measure.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-Upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

General Features

HISTORY OF INDUSTRY

The history of the acid-mine-drainage problem parallels the history of the industry and there are certain general features of the industry which have a marked influence and must be considered in any study of the acid problem.

Coal mining in the United States and in the Ohio Basin has reached its present magnitude within the last 25 years and the acid-mine-drainage problem has become increasingly acute during that time. The industry is large in itself and is vital to all industrial activity in its area. The coal-mining industry, through its drainage, damages a prosperous area at the same time that it is largely responsible for the very existence of the prosperity of that area. Location and area of the Ohio Basin coal fields are shown on figure Ac–1.

Early development.—The first recorded production of coal was in 1750, when 500 tons were mined in Virginia. There was no other important production until 1759, when a coal mine was opened on the Monongahela River opposite Fort Pitt, now Pittsburgh. In 1793 the United States produced about 63,000 tons of coal, which was mined mainly in Pennsylvania and West Virginia. In 1840, when the first Federal census was taken, coal production was approximately 2,000,000 tons. From 1841 to 1869 annual production grew to about 15,000,000 tons. From 1841 to 1869, except for 1865, Pennsylvania anthracite production exceeded total bituminous production. Since then bituminous production has been greater. Until 1873 imports exceeded exports, but since there has been a considerable export balance.

Recent trends.—In the period, roughly, 1890 to 1920 coal mining was one of the Nation's most rapidly growing industries. Production approximately doubled every 8 to 10 years, but following the First World War peak, reached in 1918, the general long-time trend has been downward. Reasons for this downward trend are believed to be (1) slower growth of population and industry; (2) fuel economy resulting from better burning equipment and careful combustion control; (3) competing fuels, mainly oil and gas. In 1900 coal contributed 89 percent of the energy derived from the mineral fuels (coal, oil, and gas) and water power. By 1937 this had dropped to 54 percent. Natural gas and petroleum contributed 43 percent and water power 3 percent. In general, the coal industry has been losing ground in most of the post-war period.

PRESENT MAGNITUDE

The annual value of coal production in five States exceeds the value of the entire annual national output of gold, silver, copper, lead, zinc, and aluminum. In West Virginia the number of men employed by coal mines exceeds the total supported by manufacturing industries, and in Kentucky the number is not much less. In Pennsylvania the bituminous coal mines normally employ more men than the steel industry.

The coal industry is a large power consumer and spends large sums annually for machinery, tools, timber, etc. In 1935 the industry's power bill was about $25,000,000 and approximately $75,000.000 were spent for supplies and equipment. Investment in the industry is estimated to be of the order of $3,000,000,000, with the bituminous coal mining investment at from 2 to 2.5 billion dollars. In Pennsylvania in 1929 the investment was approximately $500,000,000.

In 1923 the average number of men employed at operating mines, including the anthracite districts, was 862,536; in 1929, 654,444; in in 1937, 585,500. The value at the mines of the coal produced was $1,338,000,000 in 1929 and $960,000,000 in 1937. In prosperous years coal has constituted as much as 35 percent of the total railroad freight tonnage, corresponding to 23 percent of the railroad freight revenue.

Table Ac–4 and figure Ac–4 present information on the growth since 1890 and the present magnitude of the coal industry in terms of annual net tons production, value of product, employees, days worked, and number of mines in operation.

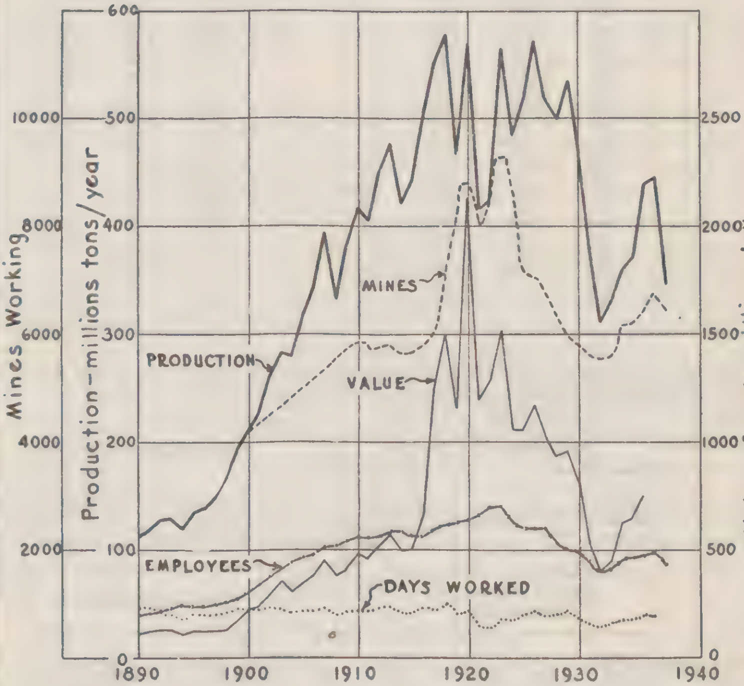
Table Ac–5 shows total coal resources and the maximum coal production by Ohio Basin States.

TABLE Ac–4.—*Acid mine drainage: Statistics of United States bituminous coal industry*

[From Minerals Yearbook, 1938]

	Production (millions of net tons)	Value (millions of dollars)	Men employed (thousands)	Average number days worked	Days lost on account of strikes	Value per ton	Net tons per man-day	Percent cut by machine	Mined by stripping (millions of net tons)
1890	111	110	192	226	---	$0.99	2.56	---	---
1891	118	117	206	223	---	.99	2.57	5.3	---
1892	127	125	213	219	---	.99	2.72	---	---
1893	128	123	230	204	---	.96	2.73	---	---
1894	119	108	245	171	---	.91	2.84	---	---
1895	135	116	240	194	---	.86	2.90	---	---
1896	138	115	244	192	---	.83	2.94	11.9	---
1897	148	120	248	196	---	.81	3.04	15.3	---
1898	167	133	256	211	---	.80	3.09	19.5	---
1899	193	168	271	234	8	.87	3.05	22.7	---
1900	212	221	304	234	5	1.04	2.92	24.9	---
1901	226	236	340	225	2	1.05	2.94	25.6	---
1902	260	291	370	230	7	1.12	3.06	26.8	---
1903	283	352	416	225	3	1.24	3.02	27.6	---
1904	279	306	438	202	8	1.10	3.15	28.2	---
1905	315	335	461	211	2	1.06	3.24	32.8	---
1906	343	381	478	213	28	1.11	3.36	34.7	---
1907	395	451	513	234	1	1.14	3.29	35.1	---
1908	333	374	516	193	11	1.12	3.34	37.0	---
1909	380	405	543	209	1	1.07	---	37.5	---
1910	417	469	556	217	35	1.12	3.46	41.7	---
1911	406	451	550	211	2	1.11	3.50	43.9	---
1912	450	518	549	223	10	1.15	3.68	46.8	---
1913	478	565	572	232	5	1.18	3.61	50.7	---

Fig. Ac-4



BITUMINOUS COAL INDUSTRY IN U.S.
Data: Minerals Yearbook
U.S. Bureau of Mines

TABLE Ac–4.—*Acid mine drainage: Statistics of United States bituminous coal industry*—Continued

	Production (millions of net tons)	Value (millions of dollars)	Men employed (thousands)	Average number days worked	Days lost on account of strikes	Value per ton	Net tons per man-day	Percent cut by machine	Mined by stripping (millions of net tons)
1914	423	493	584	195	19	1.17	3.71	51.7	1.3
1915	443	502	557	203	4	1.13	3.91	55.0	2.8
1916	503	665	561	230	4	1.32	3.90	56.5	3.9
1917	552	1,249	603	243	4	2.26	3.77	55.5	5.8
1918	579	1,492	615	249	1	2.58	3.78	55.9	8.3
1919	466	1,161	622	195	25	2.49	3.84	59.2	5.6
1920	569	2,130	640	220	6	3.75	4.00	59.8	8.9
1921	416	1,200	664	149	3	2.89	4.20	65.6	4.7
1922	422	1,275	688	142	78	3.02	4.28	63.2	9.9
1923	565	1,515	705	179	2	2.68	4.47	66.9	11.8
1924	484	1,063	620	171	7	2.20	4.56	69.5	13.6
1925	520	1,060	588	195	2	2.04	4.52	70.6	16.9
1926	573	1,183	594	215	1	2.06	4.50	71.7	16.9
1927	518	1,030	594	191	45	1.99	4.55	72.2	18.4
1928	501	934	522	203	8	1.86	4.73	73.8	19.8
1929	535	953	503	219	---	1.78	4.85	75.4	20.3
1930	468	795	493	187	---	1.70	5.06	77.5	20.2
1931	382	589	450	160	3	1.54	5.30	79.1	18.9
1932	310	407	406	146	---	1.31	5.22	78.8	19.6
1933	334	446	419	167	9	1.34	4.78	80.0	18.3
1934	359	628	458	178	---	1.75	4.40	79.2	20.8
1935	372	658	462	179	---	1.77	4.50	---	23.6
1936	439	768	477	199	---	1.76	4.62	---	28.1
1937	446	---	492	193	---	2.10	4.69	---	31.8
1938	345	---	435	---	---	2.04	---	---	---

TABLE Ac–5.—*Acid mine drainage: Bituminous coal resources as of end 1936* [1] *and maximum annual production and total production by States*

State [2]	Bituminous coal resources					Bituminous coal production			
	Original deposits	Production	Losses [3]	Reserves [4]	Mined out and lost, percent	Year of maximum production	Maximum annual production	Total production from earliest record to end 1937	Percent of total United States production
	Millions of net tons (2,000 pounds)						Net tons (2,000 pounds)		
Georgia	933	11	6	916	1.8	1903	416,000	---	---
Illinois	201,400	2,354	1,251	197,795	1.8	1918	89,291,000	2,405,891,000	12.95
Indiana	53,051	703	374	51,974	2.0	1918	30,679,000	721,091,000	3.88
Kentucky	123,327	1,163	618	121,546	1.4	1927	69,124,000	1,209,969,000	6.51
Maryland	8,043	238	127	7,678	4.5	1907	5,533,000	239,947,000	1.29
North Carolina	68	1	1	66	2.9	1922	79,000	---	---
Ohio	93,967	1,310	696	91,961	2.1	1920	45,878,000	1,335,547,000	7.19
Pennsylvania	112,148	5,777	3,070	103,301	7.9	1918	178,551,000	5,888,186,000	31.70
Tennessee	25,665	245	130	25,290	1.5	1910	7,121,000	250,197,000	1.35
Virginia	21,149	328	174	20,647	2.4	1926	14,133,000	349,074,000	1.88
West Virginia	152,544	3,132	1,664	147,748	3.1	1927	145,122,000	3,250,331,000	17.50
Total	792,295	15,262	8,111	768,922	3.0	---	---	[5] 15,650,233,000	84.25

[1] From National Resources Committee Report. Energy Resources and National Policy, p. 283.
[2] Includes entire State, parts of which are outside of the Ohio River Basin.
[3] Estimated average loss, 34.7 percent; estimated avoidable loss, 19.4 percent; estimated minimum loss, 15.3 percent.
[4] Therefore future recovery, 65.3 to 84.7 percent.
[5] Total bituminous coal production in United States from earliest record to end 1937=18,573,689,000 tons.

ECONOMIC PROBLEMS

The problems of the bituminous coal industry are associated with the abundance of the coal resources. This condition led to the opening of great numbers of mines and the development of excess

capacity. The surplus capacity and the division of the industry into many small and large units scattered over 32 States early led to severe competition. The war (1914–18) led to further expansion. Fuel shortages during and following the war were due to congestion and railway transport and strikes rather than lack of producing power. After 1923 the problems of surplus capacity, declining prices and competition began to be felt in intensified form and the coal industry entered a period of serious depression. From 1924 to 1929, when business in general was highly prosperous, bituminous coal mining suffered depression. The average sales realization free-on-board mines decreased from $2.68 per ton in 1923 to $1.78 in 1929. More than 200,000,000 tons of annual mine capacity was forced out of production and over 3,000 commercial mines were shut down or abandoned. Approximately 200,000 mine workers lost employment as a result.

The mortality rate among coal mines is notoriously high. Unfortunately, data collected do not reflect adequately this mortality because they pertain principally to the larger and more stable mining companies. It is known, however, that each year a large number of mines are abandoned, either temporarily or permanently. The United States Coal Commission in 1923 made a study of the probable life of certain mines. It was found that the average life expectancy of bituminous coal mines, excluding abandonment, ranged from about 12 years in some of the western mines to about 46 years in the Alabama mines. Bituminous coal mines of West Virginia reported a life expectancy of 42 years; those in Maryland, Kentucky, Virginia, and Tennessee, 43 years; Illinois and Indiana, 32; Pennsylvania, 29; and Ohio, 24 years. The average age of mines studied ranged from 11 years in the western fields to about 20 years in the older eastern fields.

Following emergency regulation by the Government (Food and Fuel Control Act, 1917) there has been a trend toward the conviction that the coal industry's problems are not those of a temporary recession but rather problems requiring basic adjustments. The chief lines of attack have been as follows:

(1) Self-regulation by the industry.

(2) Dual regulation by the industry in cooperation with the Federal Government.

(3) Regulation under acts passed by Congress as the Conservation Act (Guffey-Snyder Coal Act) of 1935 and the Bituminous Coal Act of 1937 (Guffey-Vinson Coal Act). (The latter is now in force.)

The outlook is for additional regulation in some form.

TYPES OF MINES

Coal mines may be classified into four types based on the method of gaining access to the coal beds:

(1) *Strip mining.*—A limited proportion of the coal is so near the surface that the overburden of rock and dirt may be removed with power shovels leaving the coal exposed for loading into cars. Strip mining usually costs less than underground methods.

(2) *Drift mining.*—A tunnel is driven into the side of a hill at the coal outcrop and the coal is mined out by following the contour of the

bed. This eliminates the need for driving tunnels into rock in order to reach the coal.

(3) *Slope mines.*—In this type of mine tunnels on grades low enough to permit mine cars to be pulled over tracks are driven into the coal beds along which active mining is to proceed. More than half of all coal mined is taken from drift or slope mines.

(4) *Shaft mines.*—A vertical opening (or shaft) is driven to the coal to be mined out and mining proceeds along the coal vein from the bottom of the shaft. The average depth of shaft mines in 1926 was 262 feet. Increase in depth magnifies problems of entry, exit, ventilation, support of cover, and drainage. Abandoned shaft mines are less of an acid problem than other types as, in many cases, acid discharge stops as the mine becomes flooded when mining is discontinued.

TABLE Ac–6.—*Acid mine drainage: Approximate percent distribution of mines by type of opening*

State	Percent			
	Shaft	Slope	Drift	Strip
Alabama	8	60	28	4
Illinois	35	38	17	10
Indiana	85	2	0	13
Kentucky	9	10	81	0
Ohio	19	20	55	6
Pennsylvania	11	13	75	1
Tennessee	10	0	90	0
West Virginia	8	8	82	2

CAUSE OF ACID FORMATION

This discussion of the cause of acid formation in mines is introduced with the observation that much is yet to be learned on this subject. There are numerous instances of record where comparable mines in the same coal bed have greatly varying acid discharges and no explanation is readily apparent. In fact, serious polluting discharges are confined to less than one-half of the mines. A proper conclusion is that research is needed and this discussion points to a possible line of attack.

Hypothesis.—According to a commonly advanced hypothesis, the iron, aluminum, and other sulfates and sulfuric acid often found in the drainage from coal mines are formed from the pyrite, marcasite, and other minerals and ores commonly found with coal deposits by the action of water and oxygen on these materials. A typical chemical reaction, using pyrite as an example of the source of sulfur, generally considered to occur, is as follows:

$$2FeS_2+7O_2+2H_2O\rightarrow 2FeSO_4+2H_2SO_4$$

Further action may then take place, in the presence of oxygen, between ferrous sulfate and sulfuric acid as follows:

$$4FeSO_4+2H_2SO_4+O_2\rightarrow 2Fe_2\ (SO_4)_3+2H_2O$$

Then:

$$Fe_2\ (SO_4)_3+6H_2O\rightarrow 2Fe\ (OH)_3+3H_2SO_4$$

Rate of acid formation.—There is very little information available regarding the effect of oxygen reduction in mine atmosphere on the rate of acid formation. However, this effect can be considered from a hypothetical standpoint, and certain tentative conclusions drawn.

In discussing the mechanism of the reaction involved in the natural oxidation of pyritic sulfur, Burke and Downes (Technical Publication No. 769, Trans. American Institute of Mining and Metallurigcal Engineers) propose the hypothesis that the observed phenomena of oxidation are probably the result of two consecutive reactions as follows:

$$FeS_2+3O_2 \rightarrow FeSO_4+SO_2 \quad (1)$$
$$2SO_2+O_2+2H_2O \rightarrow 2H_2SO_4 \quad (2)$$

The sum of these two reactions, properly balanced, is the conventional reaction:

$$2FeS_2+7O_2+2H_2O \rightarrow 2FeSO_4+2H_2SO_4 \quad (3)$$

It was further assumed by Burke and Downes that the rate of reaction (1) was extremely slow as compared to the rate of (2) and that as a consequence reaction (1) determined the rate of oxidation of the pyritic sulfur.

These assumptions were all tested experimentally and the experimental evidence confirmed the theory proposed.

Since all evidence points to the equation:

$$FeS_2+3O_2 \rightarrow FeSO_4+SO_2$$

as the controlling reaction, it should be possible to generalize the rate of this reaction, and hence the rate of acid production in terms of the concentrations of the reacting substances, FeS_2 and O_2.

According to the law of mass action, the velocity of a reaction is proportional at any moment to the molecular concentrations of the reacting components and to a constant (K) which is characteristic of the chemical nature of the reacting substances and to the temperature. At any given temperature, therefore, we may write for the oxidation of pyritic sulfur:

$$V=K\ (FeS_2)\ (O_2)^3 \quad (4)$$

V=reaction velocity
FeS_2=pyrite concentration
O_2=oxygen concentration

Since the amount of pyrite and other sources of sulfur available for reaction is large, its concentration may be considered to remain unchanged. Hence we may write—

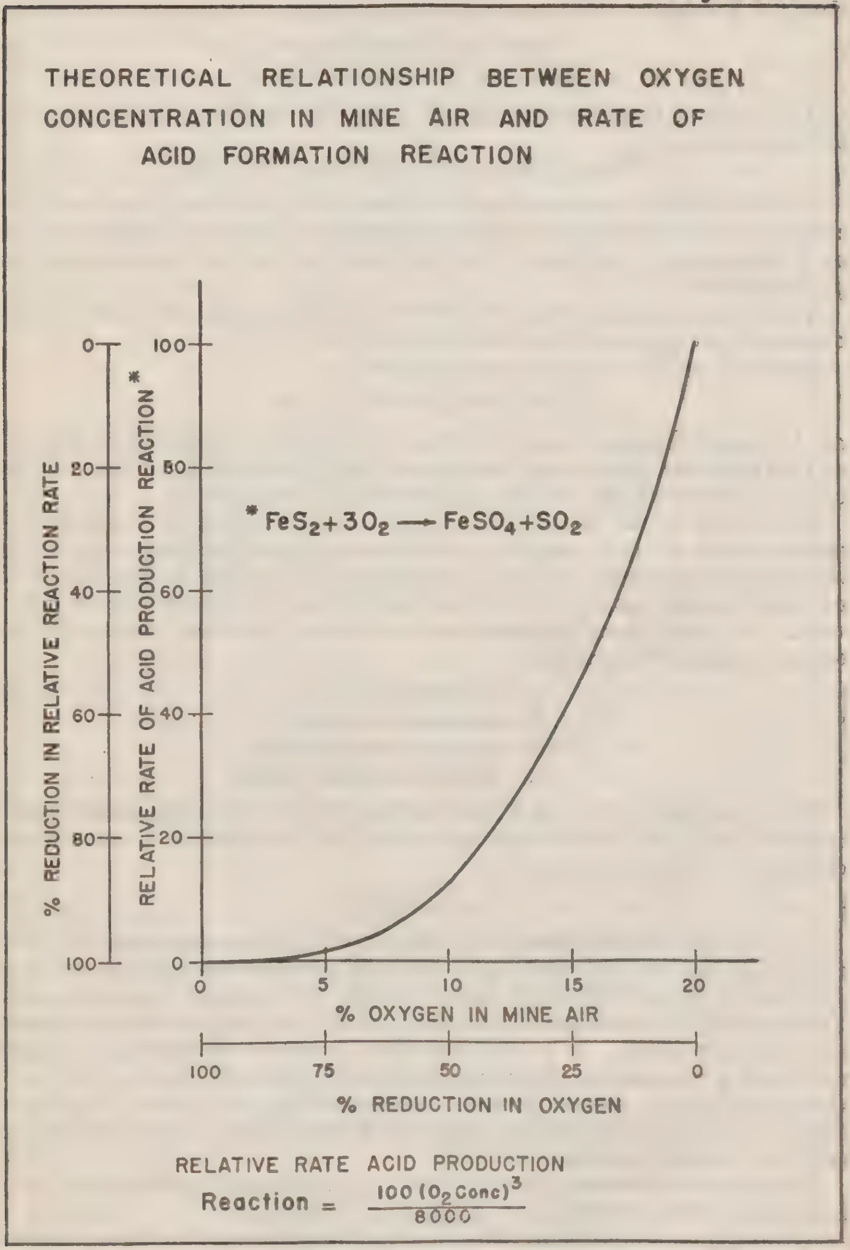
$$V=K\ (O_2)^3 \quad (5)$$

If the basic assumptions are correct, the above equation (5) indicates that the rate of reaction (1) which governs the rate of acid formation is proportional to the cube of the oxygen concentration. From analytical examination of the equation or reference to the graphical representation, it is evident that a small reduction in oxygen produces a proportionally far greater reduction in reaction rate and that a reduction of 50 percent, corresponding to about 10 percent oxygen left in the mine air, produces a reduction of roughly 87 percent in the reaction rate.

Figure Ac–5 presents a curve showing this hypothetical rate of acid formation with reduction in atmospheric oxygen.

Although this question was studied briefly by the Morgantown laboratory unit, there are no final experimental data to support the hypothesis advanced.

Fig. Ac-5


THEORETICAL RELATIONSHIP BETWEEN OXYGEN CONCENTRATION IN MINE AIR AND RATE OF ACID FORMATION REACTION
% REDUCTION IN RELATIVE REACTION RATE
0
20
40
60
80
100
RELATIVE RATE OF ACID PRODUCTION REACTION*
100
80
60
40
20
0
*$FeS_2 + 3O_2 \longrightarrow FeSO_4 + SO_2$
0
5
10
15
20
% OXYGEN IN MINE AIR
100
75
50
25
0
% REDUCTION IN OXYGEN
RELATIVE RATE ACID PRODUCTION
Reaction = $\frac{100\,(O_2\,\mathrm{Conc})^3}{8000}$

REMEDIAL MEASURES

Acid mine drainage has been an acute problem for several decades and its history involves extensive study of remedial methods and court action. Early efforts considered neutralization and recovery of by-products while more recent efforts have been toward prevention of formation of the acid and equalization of stream flow. Corrective efforts can be divided into five classes:

1. Mine sealing—Abandoned mines.
2. Mine sealing—Active mines.
3. Flow control.
4. Neutralization.
5. Miscellaneous methods.

Mine sealing—Abandoned mines.—A most promising line of attack of the acid mine drainage problem is that of preventing acid formation by sealing abandoned mines, thus eliminating most of the oxygen which is essential for acid formation and, in some measure, reducing water entering the mine.

In 1925 the United States Bureau of Mines began a series of field and laboratory studies on the subject of acid mine drainage and were later able to demonstrate the feasibility of preventing acid formation by sealing. All subsequent work has been based on the foundation of these early studies and demonstration. Large-scale sealing of abandoned coal mines in the last 7 years has confirmed the earlier work. The reduction of acid formation is based upon the principle that the exclusion of air (oxygen) from the mines will prevent the oxidation of pyrite, marcasite, and other sources of sulfur in the presence of water. Diversion of surface water from entry into mines through cracks and caves is also done in order to minimize the amount of water in the mine and prepare these entries for surface sealing. Water in the mine is allowed to drain through trapped openings.

Air sealing, to be effective, must include a maximum of surface sealing. Thereafter, with proper maintenance, a reasonable expectation is an average reduction of about 65 percent in flow, 40 percent in phenolphthalein acidity, 10 percent in methyl red acidity, and possibly 80 percent in the total quantity of acid discharged as measured in tons. There may be little immediate improvement in quality and the free-acid concentration may be increased above normal for several years. Figure Ac–3 shows expectancy curves for mine-sealing performance from the record of 100 sealed mines in West Virginia.

Sealing of abandoned coal mines was begun on a large scale in 1933. The program was instituted and presented through the combined efforts of the Ohio River Board of Engineers, the United States Public Health Service, various State health departments, and Federal relief agencies. Work was carried on intermittently until 1935 when the program was placed on a regional basis under the Works Progress Administration and the United States Public Health Service with the State health departments cooperating.

The program has been carried on until the present time (1940) in West Virginia, Maryland, Ohio, Alabama, Tennessee, and Indiana. Although far from completed, work was stopped in Pennsylvania and Kentucky in 1938. Work in Illinois has been largely completed. No work has been done in Virginia.

The mine-sealing program in the past has been a relief measure and, as a result, activities have tended to concentrate in areas of greatest relief need rather than in areas of greatest acid-control need. Considered primarily as a relief measure, this tendency has been proper. In general, a cost limitation of $10 per ton per year has been in effect. Such economical projects should be attacked first. Indications are that extension of this cost limitation to a somewhat higher figure is justified particularly in critical areas. The present mine-sealing authorization is for abandoned mines and does not cover areas that are connected with an active ventilation system. In a truly comprehensive program such areas should, in many cases, be brought within the range of control.

Any stream-improvement program, be it an organic pollution remedial measure or one for acid control, requires a continuing effort in the form of sewage or industrial waste treatment plant operation or mine-seal inspection and maintenance. This feature is of particular importance in connection with mine sealing. In some States, provisions for maintenance are inadequate and the seals are reported to be breaking down. A mine-sealing program should include provision for inspection and maintenance or the program will be of only passing benefit.

Inspection is estimated at 2 percent. Maintenance may be 15 percent or higher for a few years reducing to a low figure as the seal becomes stabilized. A range of from 7 to 10 percent will probably represent average conditions. If interest (3½ percent) and amortization (0.7 percent based on a 50-year life and 3½-percent interest) are added, annual charges will total about 15 percent.

Mine sealing—Active mines.—In carrying out possible air-sealing activities in connection with active mines, it is necessary to enter the mine where active mining operations are still in progress. This is properly the jurisdiction of the mining departments and any proposed activity is a matter for State mining department supervision. However, acid from operating mines presents a pollution problem and is therefore also within the jurisdiction of pollution control agencies. This problem, therefore, requires close coordination of the activities of the two administrative agencies.

The acid produced in active mines represents a large proportion of the total mine-acid production and to date no extensive attempts have been made to offset this load. However, based upon the demonstrated success of sealing abandoned mines, the possibility of minimizing to a great extent the acid production in active mines by surface sealing for diversion of surface water and air sealing of worked-out sections in the mine is worthy of careful consideration.

With orderly panel developments of mines and the use of barrier pillars to minimize the number of openings to various portions of the mine, air-sealing of worked-out sections can be accomplished at low expense. Both surface and air-sealing would reduce acid production and the results of such sealing would be of great benefit not only in reducing stream pollution but also in lowering mine operating costs. Direct benefits to mine operators that would accrue through sealing may be summarized as follows:

(1) Decreased pumpage: This would result mainly from surface sealing of cracks and caves and consequent diversion of surface water from the mine. Pumping costs are a substantial operating expense

item at most large mines and any reduction in water entering the mine would result in a significant saving.

(2) Lower costs for ventilation: An unsealed worked-out section requires ventilation to eliminate the hazards of gas (methane) which is encountered in many mines. This results in considerable ventilation expense chargeable to areas no longer yielding any return. If these sections were air-sealed by the conventional method involving the use of a water trap, ventilation would no longer be required. Where excessive amounts of gas are encountered it would be necessary as a safety measure to provide for pressure relief by suitable means.

There may also be a benefit due to a lesser acid quality of the water but, as pointed out, this is not certain at least for a period of several years.

The net reduction in quantity of water, ventilation area, and possibly quality of water on a conservative basis is ample to make sealing of worked-out sections of active mines attractive. Although detailed studies are not available, it is quite possible that savings would be sufficient to amortize the required investment. Experience with abandoned mines clearly indicates that improvement is possible in the discharge from worked-out sections of active mines. A suitable actual demonstration is needed to facilitate adoption of the proposal in general practice.

The sealing of worked-out sections is permissible under the mining laws of several States provided that such seals do not cause impoundment of large quantities of water under any considerable head. Such a condition would obviously be hazardous to nearby active workings. Fortunately, sealing causes no dangerous impoundment since the water can pass readily through the air seal. Sealing of worked-out areas has been practiced to a limited extent but with considerable success in one State.

Mine sealing—Economic considerations.—The cost of sealing a mine is roughly proportional to the number of acres of the coal measures which have been mined out. However, certain mines, for reasons not thoroughly understood, produce far more acid per acre mined out than others even though all may be relatively close to each other and may have worked the same coal seams. Thus the cost of sealing a low acid producing mine may well be as high or higher than the cost of sealing a comparable mine producing much more acid. This suggests that a maximum sealing cost, based on the cost per unit weight of acid sealed, be established. Under the present program this has been set at approximately $10 per ton per year. As might be expected, State-wide averages for sealing work to date, as shown in table Ac–2, have been less than this figure. However, use of such a limiting figure is restricted to large areas; and when the problem of economical use of mine-sealing funds is viewed on the basis of small areal units, such as counties or small watersheds, the difficulty of applying any rigid economic standard becomes apparent. In such cases the answer to the question of how much should be spent per ton of acid sealed should be based on an estimate of how much acid removal is worth from the standpoint of various water uses. For example, on a small stream receiving the drainage from only a few abandoned mines and no other pollution, the value of acid removal or reduction might well be many times as great as the corresponding

value on a similar stream subject to heavy pollution from many different sources. In the latter case, the economic limit might well be far less than any State-wide or regional average standard while in the former it conceivably could be much greater.

Flow control.—In many streams the natural alkalinity of the water is ample during normal times to neutralize the acid-mine drainage load placed upon it and leave a satisfactory residual alkalinity. However, at certain times, the flow of the stream may not be sufficient to absorb the load, and normal aquatic life requiring a continuous satisfactory habitat may be damaged or destroyed. It follows that if alkaline water from storage can be added at such times the damage caused by the acid-mine-drainage load will be greatly reduced.[1]

The construction of a reservoir for the sole purpose of supplying flows to neutralize acid-mine drainage would be unduly expensive. However, there has been a trend in the past decade toward the construction of multipurpose reservoirs or, more commonly, toward the multipurpose use of what are primarily flood-control reservoirs. Effectiveness for the specific purpose of acid control is somewhat reduced under these conditions, but the neutralization of acid-mine drainage need justify only a part rather than the whole cost of a reservoir. Flow control as a means of correcting acid-mine-drainage conditions, particularly in leveling off fluctuations, appears worthy of serious consideration.

Mine sealing versus flow control.—During the past few years there has been considerable mine-sealing activity in West Virginia on the Monongahela watershed. At the same time the Tygart Dam has been constructed and operated to maintain increased low flows. Both of these activities have had a beneficial effect on the stream and any complete program of acid control will probably require the use of both control methods.

The essential difference in the operation of the two acid-control methods is that mine sealing reduces the acid load throughout the year while flow control causes no acid reduction but simply stores water during periods when excess alkalinity is available and saves it for discharge during subsequent periods when acid conditions are serious. Reservoir operation may also smooth out objectionable day-to-day acid surges. Acid reduction by sealing may vary considerably from month to month and, as a rule, is more effective during the low-flow months.

As multipurpose use of a flood-control reservoir involves no appreciable storage from one year to the next, it is safe to assume that such a reservoir will not change the total tons of acid discharge during the year. In other words, the reservoir stores the alkaline flow for later discharge during an acid period in the same year. This means that annual average tons of acid discharge can be plotted to show trends with the effect of storage dams eliminated.

[1] In waters containing mine drainage, there are theoretical considerations that indicate that it is not strictly correct to deduct alkalinity values from acidity values. The low alkalinity values obtained in acid mine river samples may be the result, in many cases, of partial and incomplete hydrolysis of the iron salts contained therein. When such samples are added to samples which are already acid a dilution of the unhydrolyzed iron salts would occur which would hasten the hydrolysis and establish a new equilibrium. Consequently, river samples which are slightly alkaline and contain iron salts will not always be capable of stoichiometrically neutralizing samples which are already acid. Because of a lack of sufficient data it is impossible to calculate the exact result of mixing samples of this kind in terms of alkalinity or acidity. However, the present procedure is considered satisfactory for the practical purpose of presenting the results as it is the simplest for purposes of presentation and not believed to be greatly in error.

In order to illustrate the effect of the two control methods, in simplified form, figures Ac–6, Ac–7, and Ac–8 have been prepared. These figures are based on a stream whose weighted average daily quality is neutral and which approaches the quality of the Monongahela River about the year 1920, as measured by the methyl orange indicator. Figures Ac–6 and Ac–7 show identical effects of the two methods of control as far as reductions of peak acidity and acid days are concerned. Figure Ac–8 shows the effects of the two methods of control added together to eliminate acid conditions in the stream.

The principal point of difference illustrated by figures Ac–6 and Ac–7 is that mine sealing reduced the weighted annual average acidity while reservoir operation equalizes the discharge of alkalinity. The principal point illustrated by figure Ac–8 is that the effects of the two methods of control actually can be added together to correct situations where either method alone might not prove adequate.

The functions of the reservoir, as stated, are to equalize the flow of natural alkalinity available for acid neutralization and to eliminate day-to-day acid surges. However, as a reservoir does not affect the weighted average quality of the discharge, no amount of reservoir operation can make an alkaline stream of one whose average quality is acid.

Mine sealing, on the other hand, can be used to attack practically any situation with some hope of restoring a stream to alkaline conditions. While mine sealing cannot be applied to acid from active workings, as can reservoir operation, it should be pointed out that probably not over 10 percent of the total acid load comes from working areas. A stream restored to average alkalinity by sealing operations may still suffer from acid surges for which a reservoir is needed. In general, the two methods of acid control supplement one another.

Flood-control reservoirs.—The discussion of flow control thus far has been based on the assumption that the reservoir has been operated solely for the control of acid. Under such circumstances, alkaline water is stored only when there is an excess or balance of alkalinity in the stream and is discharged whenever the stream becomes acid. When the primary purpose of a storage reservoir is flood control, such ideal operation is not always possible. Using the Tygart Reservoir as an example, the plan of operation is to hold the reservoir at a low level (elevation 1,010) for flood protection until about April 10 and to fill the reservoir to elevation 1,094 from April 10 to about June 15, leaving a lesser capacity available for flood control during and after this period. From about July 1 to December the reservoir is used to increase low flows leaving the reservoir at a low level at the end of the year for flood control. Figure Ac–9 shows Tygart Dam operation in 1939 together with the pool elevation guide line.

Tygart Dam has, without doubt, had a beneficial effect on the water supply of Morgantown, W. Va., 50 miles below on the Monongahela River. However, the main storage takes place in April, May, and June rather than during periods of excess alkalinity. Figure Ac–10 shows, as near as can readily be computed, the effect of Tygart Dam on the acidity of this supply by months from July 1938 through 1940. This shows that during the six main storage months in this record, alkalinity was available within the storage requirements during 3

Fig. Ac-6

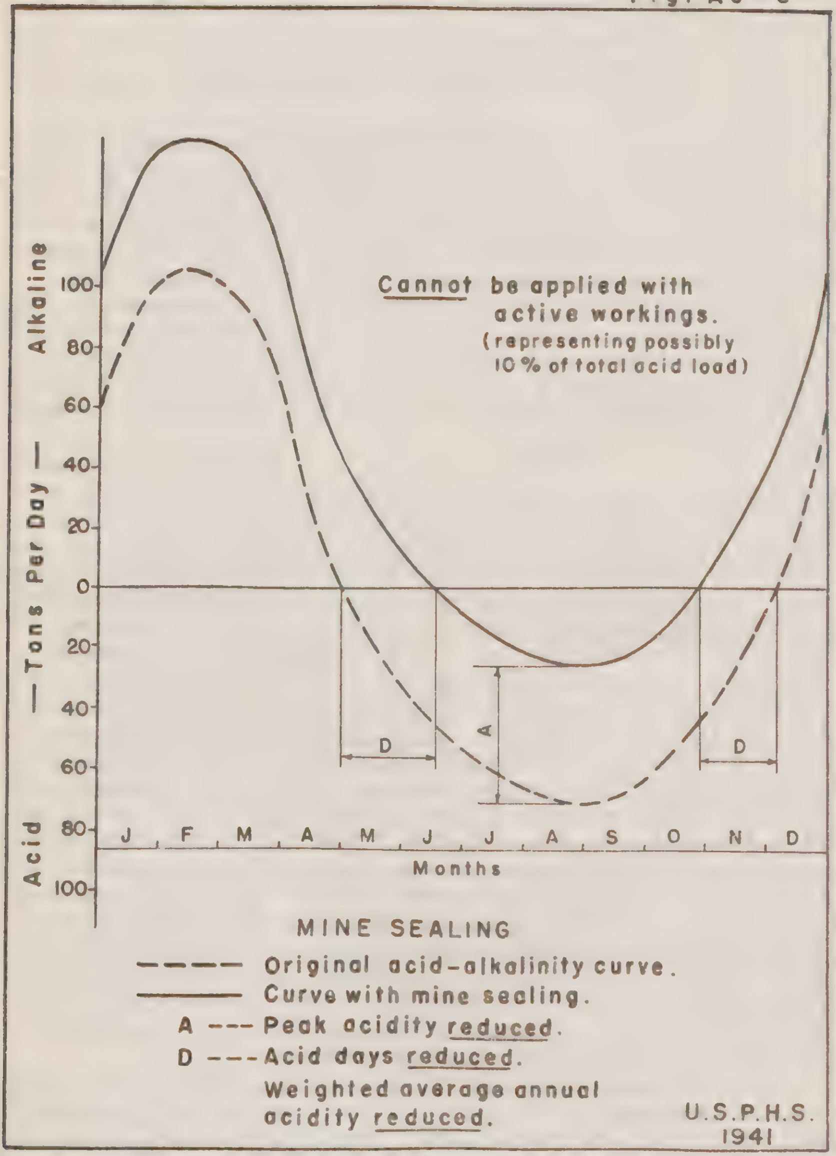
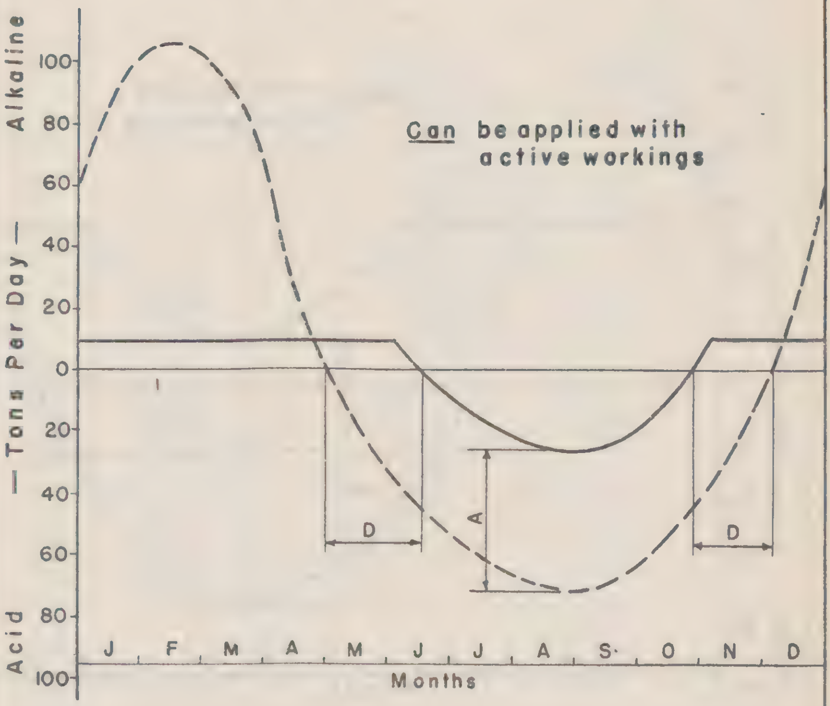

Cannot be applied with active workings.
(representing possibly 10% of total acid load)
Acid — Tons Per Day — Alkaline
100
80
60
40
20
0
20
40
60
80
100
J F M A M J J A S O N D
Months
D
A
D
MINE SEALING
Original acid-alkalinity curve.
Curve with mine sealing.
A --- Peak acidity reduced.
D --- Acid days reduced.
Weighted average annual acidity reduced.
U.S.P.H.S. 1941

Fig. Ac-7



RESERVOIR OPERATION

– – – – Original acid-alkalinity curve.

——— Curve with reservoir operation.

A --- Peak acidity reduced.

D --- Acid days reduced.

Weighted average annual
acidity unchanged.

U.S.P.H.S.
1941

Fig. Ac-8

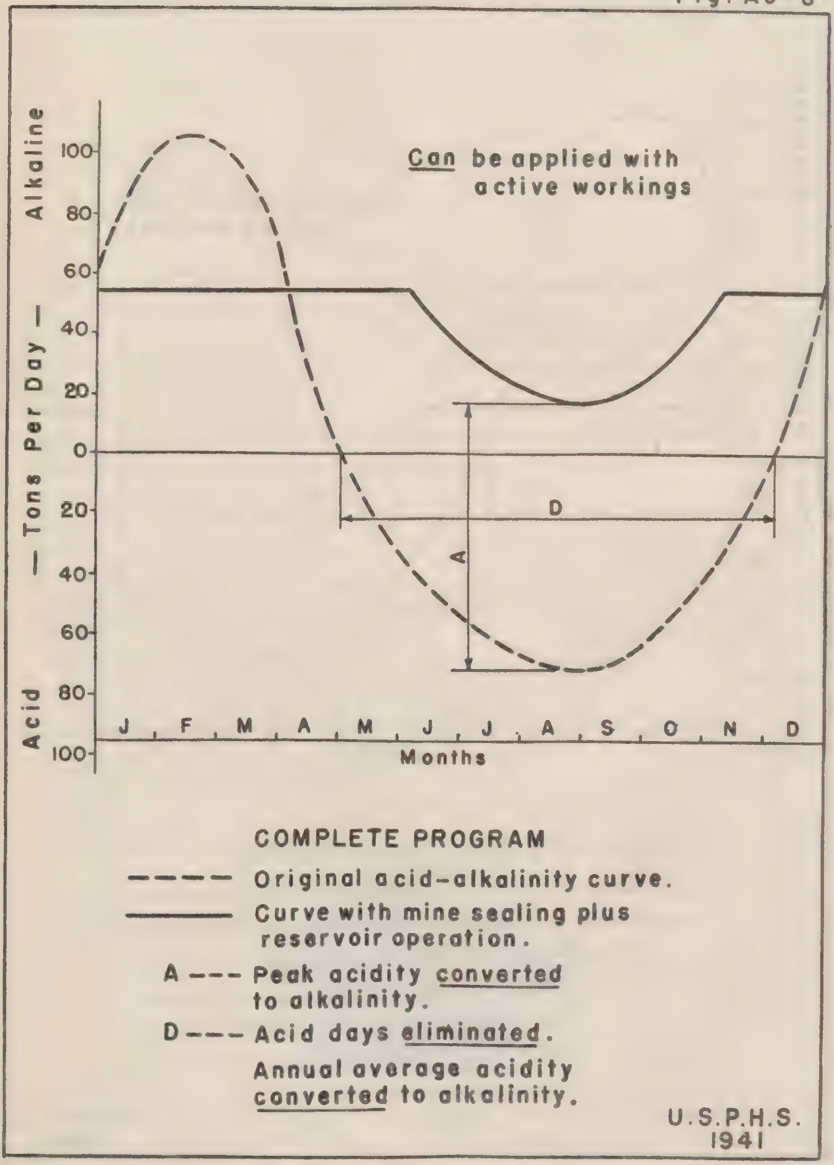
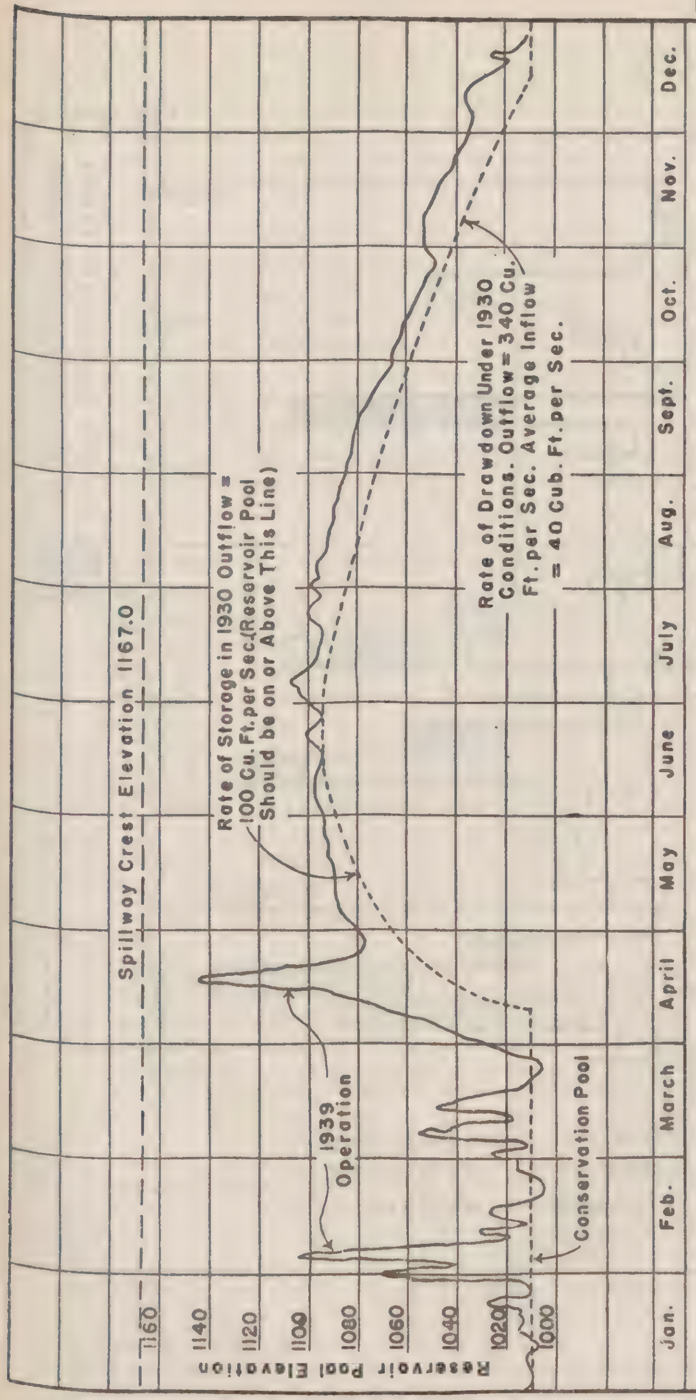

Can be applied with active workings
Alkaline
— Tons Per Day —
Acid
100
80
60
40
20
0
20
40
60
80
100
D
A
J F M A M J J A S O N D
Months
COMPLETE PROGRAM
Original acid-alkalinity curve.
Curve with mine sealing plus reservoir operation.
A --- Peak acidity converted to alkalinity.
D --- Acid days eliminated.
Annual average acidity converted to alkalinity.
U.S.P.H.S. 1941

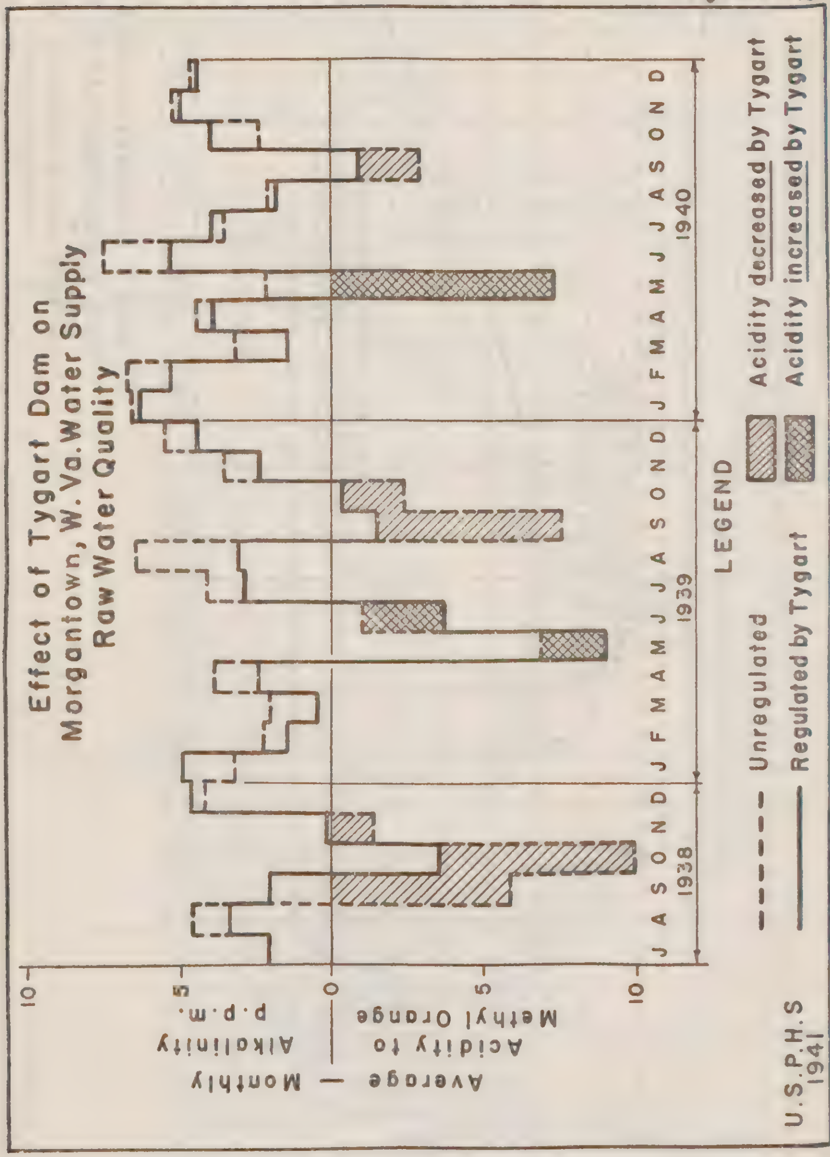
Fig. Ac-9



TYGART RESERVOIR OPERATION
POOL ELEVATIONS YEAR OF 1939
Data from U.S. Engineer Office
Pittsburgh, Pa.

U.S.P.H.S.–1941

Fig. Ac-10



Effect of Tygart Dam on
Morgantown, W. Va. Water Supply
Raw Water Quality
Average — Monthly Alkalinity p.p.m.
Average — Acidity to Methyl Orange
10
5
0
5
10
J A S O N D
1938
J F M A M J J A S O N D
1939
J F M A M J J A S O N D
1940
LEGEND
Unregulated
Regulated by Tygart
Acidity decreased by Tygart
Acidity increased by Tygart
U.S.P.H.S
1941

months but was not available during the other 3 months. Therefore, during these latter 3 months the acidity at Morgantown was actually increased by Tygart Dam operation. Against this, there were 6 months in the 30-month period when the acidity was decreased and during two of these the acid was neutralized.

It is of interest that Tygart Valley waters were substantially reduced in acidity by mine sealing before the dam was put in operation, thus illustrating again how the two control methods supplement one another.

Neutralization.—For many years consideration was given to abatement of the mine acid pollution problem by chemicals such as lime or limestone for neutralization. However, such treatment methods proved to be impractical due to the expense of operation and initial treatment-plant construction. Estimates indicate that to treat all acid mine drainage in Pennsylvania, Maryland, Ohio, and about half of West Virginia would require an initial plant investment of approximately $242,000,000, with annual operating costs of about $132,000,000. This annual operating cost compares favorably with the annual value of all the bituminous coal produced in Pennsylvania in recent years and amounts to an annual charge of about 50 to 60 cents per ton of coal produced yearly in the States named. For the entire United States the cost has been estimated at about $330,000,000 for plant construction with operating costs at $180,000,000 per year. No readily marketable byproducts result from neutralization processes to help defray expense. In addition, the difficulty of disposing of the enormous amounts of iron and aluminum hydroxide sludge produced by neutralization is considered to be significant.

Miscellaneous methods.—A number of miscellaneous acid-control methods have been used or suggested. One of these is an established policy of refraining from discharging acid waters to streams previously uncontaminated. In some cases this is highly desirable and the policy might be advantageously expanded in special cases.

Flooding or impounding is the natural result of discontinued pumping with abandonment of shaft mines. In other cases flooding appears dangerous and impractical, as well as being a poor substitute for mine sealing.

Regulation of mine openings and concentration of discharge has little over-all effect. A certain acreage of coal will be mined each year and the acid production will not be changed whether the coal is mined in new territory or old. Concentration of acid pollution brings about critical conditions. Dispersion may keep the acid within controllable limits.

STATUTES AND COURT DECISIONS

Legal efforts to control acid mine drainage through enactment of State laws or through court action have made little progress. Of the two legal approaches, court action has been the more successful. Ohio, Pennsylvania, and West Virginia have laws specifically exempting mine drainge from control while in one instance, the *Indian Creek case*, court action was successful in obtaining relief.

Statutes.—The mining laws of the States of the Ohio River Basin are administered by the State mining departments whose duties are to execute and enforce the State mine-inspection laws, enacted for the safety of persons employed within or at the mines and the protec-

tion of mine property and other property used in connection therewith. It is the duty of the chief mine inspector to report improvement of methods, conditions, development, and progress in mining with reference to health, safety, economy, and conservation.

The States of Ohio, Pennsylvania, and West Virginia have sanitary regulations pertaining to the disposal of sewage and industrial wastes but in these States acid mine drainage is exempt until treatment and/or disposal methods are developed. The mining laws of West Virginia provide that mine drainage waters be free from pollution by human and animal excrement or substance deleterious to health.

The mining laws of Kentucky, Tennessee, Virginia, and West Virginia state that it is the duty of the mine foreman to remove water from working places within the mines. Alabama, Georgia, Illinois, Kentucky, Pennsylvania, and North Carolina provide regulations in their mining laws for eminent domain, that whenever any mine or mine place shall be so situated that it cannot be conveniently worked without a ditch to drain or convey water thereto, the owner or operator may construct such ditch when he complies with the law of eminent domain. The Kentucky law states—

> the water so drained or pumped from such mines shall be drained as directly as practicable to adjacent streams or watercourse by means of ditches, flumes, pipes, sewers, or other adequate provisions.

The Pennsylvania mining laws provide for the sealing of abandoned mines but do not prescribe the method. The laws of Indiana, Ohio, and Virginia permit the sealing of worked-out sections of active mines while West Virginia does not prohibit this sealing. Ohio and other States provide for closing and/or fencing abandoned mine openings to prevent entrance thereto.

Regulations of Alabama, Maryland, Pennsylvania, and Virginia provide for the reopening of old and abandoned mines and for the drainage of water therein. All States have safety regulations governing the approach to abandoned mines or worked-out sections which may have dangerous accumulated water or gas.

Table Ac–7 summarizes the State laws on certain features of the acid mine drainage problem. In general, it appears that there are as many laws hindering the control of acid mine drainage as there are assisting this control.

TABLE Ac–7.—*Acid mine drainage: Summary of State mining laws pertaining to acid mine drainage*

State	Mining regulations providing for—		
	Sealing of abandoned mines	Sealing of abandoned workings of active mines	Exempting acid mine drainage from regulation
Alabama			
Georgia			
Illinois			
Indiana		Yes	
Kentucky			
Maryland			
North Carolina			
Ohio		Yes	Yes.
Pennsylvania	Yes		Yes.
Tennessee			
Virginia		Yes	
West Virginia		Not prohibited	Yes.

Court Decisions.—The two court decisions relating to acid mine drainage, the *Indian Creek case* and the *Sanderson case*, are basic in character and rather widely known. In the *Indian Creek case*, the Court found in favor of a water company as the water was considered more important to the Commonwealth than the coal. In the *Sanderson case*, the reverse was true, as the Court found in favor of the coal mines as the coal was considered more important. The following is in part, from a published summary of a discussion of these two cases.

Indian Creek case.—The Mountain Water Supply Co. was organized in 1905 and appropriated the water of Indian Creek to supply the Pennsylvania Railroad System in southwestern Pennsylvania, as far west as Pittsburgh. A large storage dam was built about 4 miles from the mouth of Indian Creek. The drainage area above this point is 110 square miles, of which 55 square miles were underlaid with the lower coal productive measures. In addition to supplying the railroad company, the water company furnished water to several municipalities in western Pennsylvania, supplying about 75,000 people. Active coal development began on a large scale, and it was apparent that this important water supply eventually would be damaged or destroyed if mining continued. The water company appealed to the courts for an injunction to restrain the coal companies from discharging acid drainage into Indian Creek above the dam.

The Fayette County court decided there was no public use of the water and that preventing the mining companies from discharging water into Indian Creek would deprive them of the use of their property. The court refused to grant an injunction restraining the mining companies from discharging mine water into this stream. The Pennsylvania Supreme Court reversed the lower court declaring that it was not a question of property rights, but that it was a nuisance to pollute the stream and that the mining companies should not, after a certain period, discharge the mine water into Indian Creek or its tributaries above the dam of the water company. This opinion, which was concurred in by the United States Supreme Court, states:

> It is controlled by one fact and a single equitable principle; the fact that the stream has been polluted, and the principle that this creates an enjoinable nuisance if the public uses the water.

Sanderson case.—In 1886 Sanderson bought property in the city of Scranton through which flowed Meadow Brook, a pure, unpolluted stream. He built a dam and developed a water supply for his own use. About the same time Pennsylvania Coal Co. opened a coal mine which soon produced acid mine drainage destroying the use of the brook water. Sanderson brought suit for damages resulting from loss of the stream. The case was twice tried in courts of Lackawanna County, Pa., and was twice before the Supreme Court of Pennsylvania. The supreme court decision affirmed the lower court's award of damages to Sanderson; Justice Paxon filed a strong dissenting opinion, which was sustained in the second supreme court decision.

The court took the position that if Sanderson could collect damages every riparian owner thus affected could do likewise and if they could collect damages they could also enjoin the pollution of streams by mine drainage which would practically stop all mining operations except by consent of the lower riparian owners; that trifling inconvenience to particular persons must sometimes give way to the

necessities of a great community, especially where the leading industrial interest of the State is involved. The court further stated in its opinion that the coal company was making the natural and ordinary use of its property, and that Sanderson with others was then securing an abundant supply of pure water from other sources, but that it would not say that a case—

may not arise in which a stream, from such pollution, may not become a nuisance, and that the public interest as involved in the general health and well being of the community may not require the abatement of that nuisance.

The difference between the Sanderson and the Indian Creek decisions is that Sanderson, an individual who had access to another good supply of water, was not permitted to stand in the way of Pennsylvania's greatest industry whereas in the *Indian Creek case* the public, also represented by the Commonwealth, was fighting to preserve one of the last available pure water supplies in the State, and the decision merely carried out one of the principles enunciated in the Sanderson decision.

Presentation of Field Data

MINE ACID LOADS

In collecting information on mine acid loads in the Ohio River Basin valuable assistance was furnished by the personnel of the Office of Mine Sealing. In certain cases, records were summarized from State files but in all cases the information was checked by Mine Sealing personnel familiar with the work in the various States. This personnel is of the opinion that certain portions of the load estimates are based on less than satisfactory complete data. However, it is agreed that the estimates are the best available and that improved estimates would require extensive sampling and gaging studies, neither possible nor justified, for the purpose of the Ohio River pollution survey.

Magnitude.—Table Ac–1 indicates the magnitude of the acid mine drainage problem by States and major tributary basins in terms of tons of acid produced annually by active, marginal, and abandoned mines, the estimated present status of the remedial measures of mine sealing and the estimated portion of the total acid load which may be removed economically by sealing methods under restrictions of 1940.

Figure Ac–2 shows, in graphical form, the magnitude of the original mine acid loads and the reduction by present and possible future economical mine sealing under 1940 restrictions in each State. As there are two distinct coal fields in Kentucky, one in the east and one in the west, two symbols have been used in this State, one for each coal field.

Intensity.—The intensity of the acid load is given on table Ac–1 in terms of tons per square mile per year. These figures show strikingly that the problem is acute in the areas drained by the Monongahela, Youghiogheny, and Kiskiminetas Rivers and in the States of Pennsylvania and West Virginia. The loads given are prior to sealing and more recent residual loads are, in certain cases, much less.

Pickle acid comparison.—Table Ac–8 presents a summary of mine acid loads (to phenolphthalein) in 1,000 pounds per day and compares these figures with the free acid loads from waste pickle liquor. The

pickle liquor free acid load shown as 3.4 percent of the present mine acid load does not include the iron salts which are probably hydrolized to some extent in solution to form sulfuric acid. This latter acid, which must be included in any neutralizing plant, may vary from a minor item to 8 or 10 times the free acid load depending on the hydrolysis equilibrium. Acid pickle liquor wastes are important in local areas particularly in the vicinity of outfalls but they are less of a general problem than acid mine drainage.

TABLE Ac–8.—*Acid mine drainage: Summary by tributary drainage basins, of original mine acid loads and mine acid loads after present sealing and complete sealing program under 1940 restrictions together with comparison with waste pickle liquor free acid loads*

Tributary drainage basin	Mine acid loads as $CaCO_3$: Original	Mine acid loads as $CaCO_3$: After mine sealing: Present (A)	Mine acid loads as $CaCO_3$: After mine sealing: Complete program	Free acid load from pickle liquor as $CaCO_3$ [1]	Free acid load from pickle liquor as $CaCO_3$ [1]: Percent of (A)
	1,000 pounds per day				Percent of (A)
Allegheny River except Kiski	456	355	177	17	4.8
Kiskiminetas River	1,764	1,703	975	10	.6
Allegheny River total	2,220	2,058	1,152	27	1.3
Monongahela except Youghiogheny	3,841	2,461	1,827	57	2.3
Youghiogheny River	1,204	1,079	624	------------	0
Monongahela River total	5,045	3,540	2,451	57	1.6
Beaver River	95	83	47	64	77.0
Little Kanawha River	4	2	2	0	0
Kanawha River	180	105	93	0	0
Guyandot River	111	60	52	0	0
Big Sandy River	334	253	153	0	0
Muskingum and Hocking Rivers	1,182	681	577	11	1.6
Scioto River	132	98	59	0	0
Little Miami River	0	0	0	0	0
Licking River	([2])	------------	------------	0	0
Miami River	0	0	0	55	------------
Kentucky River	230	167	115	0	0
Salt River	0	0	0	0	0
Green River	419	336	210	0	0
Saline River	([2])	------------	------------	0	0
Tradewater River	43	39	21	0	0
Cumberland River	1,451	1,073	563	0	0
Tennessee River	209	120	61	0	0
Wabash River	600	343	176	2	.6
Main Ohio River:					
Pennsylvania	271	221	139	32	14.5
Ohio	622	486	266	31	6.4
West Virginia	147	97	87	48	49.5
Kentucky	94	73	46	9	12.3
Indiana	72	38	36	------------	0
Illinois	14	13	7	------------	0
Main Ohio River total	1,220	928	581	120	13.0
Unclassified, Virginia	103	103	42	------------	------------
Total Ohio River Basin	13,578	9,989	6,355	336	3.4
Percent waste pickle liquor acid of mine drainage acid	2.4	3.4	5.3	------------	------------

[1] Does not include iron salts.
[2] Slight.

MINE SEALING COSTS

Table Ac–2 presents State-wide and Ohio River Basin figures for the cost of mine sealing to date and cost estimated to complete a program of mine sealing under 1940 restrictions. The complete

program mentioned here and in other discussions contemplates sealing all acid discharges that can be sealed for a cost not exceeding approximately $10 per ton per year. As pointed out in later discussions, this cost limitation can be extended and such extension appears justified.

MINE ACID EFFECTS

Mine drainage, containing sulfuric acid and the acid salts (sulfates) of iron and aluminum, which reaches the surface streams in the bituminous coal-mining areas in Pennsylvania, West Virginia, Maryland, Ohio, Indiana, Kentucky, Illinois, and Virginia, is one of the most damaging industrial wastes in the Ohio River Basin. Pollution from this source is greatest in Pennsylvania and West Virginia, the two largest bituminous coal-producing States. Unlike most damages caused by sewage and organic industrial wastes, most damages from acid mine drainage are real and tangible and can be estimated with a reasonable degree of accuracy.

The immediate effect of acid mine water on small and large streams is to change the chemical character of the water. More specifically, acid mine drainage will—

(1) Destroy or materially reduce the natural alkalinity resulting in conversion of carbonate to noncarbonate hardness.
(2) Lower the pH.
(3) Increase the total hardness.
(4) Add objectionable amounts of iron, manganese, aluminum, and sulfate to the water.

These changes result in damages to the stream, both tangible and intangible. The tangible damages which have been evaluated are briefly as follows:

(1) The water is rendered expensive and difficult to treat for municipal and industrial use.
(2) The water is rendered highly corrosive to ordinary steel or iron structures and equipment such as culverts, bridges, locks, boat hulls, steel barges, pumps, and condensers. Concrete structures are also damaged.

The intangible damages, which are nonetheless real and important, are briefly as follows:

(1) The streams are often rendered unsatisfactory for normal recreational use; i. e., fishing, boating, swimming.
(2) The biological processes and characteristics of the streams are substantially altered. Normal biological activity is retarded. In other words, the stream is no longer the habitat for desirable aquatic life.
(3) Chemical precipitation action of iron and aluminum salts, combined with the low velocity in the navigable channels, results in the heavy deposition of sewage solids particularly below Pittsburgh, and the ensuing flush-out by high water causes a wide fluctuation in quality, as reported by water-plant operators, to pass down the Ohio River to the great detriment of public water supplies and hazard to the public health.

Acid mine drainage has served as a deterrent to the abatement of other types of pollution, particularly of an organic nature. There is

no great incentive nor, in fact, justification for sewage treatment or the correction of organic industrial pollution if the result will be a stream that remains unsuitable for any use other than the disposal of mine waters. While other sections of the country have made substantial progress in the restoration of streams, the mining areas are notable for the few sewage-treatment plants to be found.

The germicidal, inhibiting, and other effects of the acid may prevent odor nuisance, a point which has been the subject of considerable discussion. However, the visual nuisance may remain and from a public-health standpoint or in the protection of public water supplies, acid mine drainage is not a dependable safeguard. During a freshet the rapid increase in flow may bring sufficient alkalinity to neutralize the acidity and eliminate the germicidal effect. This would happen at the same time that accumulated sludge deposits are being flushed out and the greatest need for a germicidal effect occurs. A water plant depending on acid mine drainage germicidal action would be operating under a greatly reduced factor of safety.

EVALUATION OF DAMAGES

Damages caused by acid mine drainage differ from most damages caused by organic pollution in that many of them have a definite quality and are capable of accurate determination in dollars. While damages due to impaired recreation, the creation of a nuisance and hazard to the public health are equally real and important, a monetary estimate of the extent of such damages must be based on assumptions of the person making the estimate. No assumptions are necessary to determine the cost of chemicals for neutralizing a raw water or removing noncarbonate hardness. The cost of removing a barge or towboat from service for extra painting and the cost of that painting can be determined with accuracy.

The damages considered in this section are confined to those capable of definite and accurate estimation in dollars. A summary of the damages estimated is given in table Ac–3. Damages to river and harbor structures and to the floating plant of the United States Engineer Department are based on the years from 1937 to 1939, inclusive, and corrected to the year 1940. All other damages are based on average experience during the past 10 years and corrected to 1940.

The damages shown on table Ac–3 for 1940, 1950, and 1960 are all based on 1940 use or on present navigation activity, water supply pumping, and other items. The 1960 estimate might well be increased from 25 to 50 percent to include an increment of increased use that is a normal expectancy.

Information for the evaluation of damages by acid mine drainage were collected, in part, during the regular industrial and municipal field investigations and in part by the special staff assigned to the acid mine drainage problem. Knowledge and appreciation of the damages are quite general, but carefully assembled reliable data on the extent of damages in dollars were available in only a small percentage of cases.

However, these relatively few cases were such that unit factors could be determined and applied in other locations with adjustments for the size of the establishment and the severity of the acid problem.

Supporting data are too voluminous for inclusion in this supplement. In general, the methods used are as follows:

Water supplies.—Damages to water supplies consist of, first, the cost of chemicals required to neutralize the free mineral acids and at least part of the acid salts; and, second, the chemicals required to convert noncarbonate hardness caused by acid mine drainage back into its original carbonate form. Lime is needed for domestic, boiler, and industrial cooling waters to neutralize the acidity. Soda ash is needed to convert the noncarbonate hardness in the domestic and boiler waters only.

The quantities of water used for domestic and industrial purposes were taken from the field survey reports. Information on raw-water quality for the past 10 years was obtained from water-plant records. Particular emphasis was placed on the records of the McKeesport water plant on Monongahela River water and on the records of the Pittsburgh filter plant at Aspinwall on Allegheny River water.

Neutralization is necessary to prevent corrosion or reduce it to a normal condition that would exist in the absence of acid mine drainage. Neutralization of the free mineral acids or the acidity to methyl orange would leave a water with pH 4.0. This is lower than normal and would still cause excessive corrosion. To raise the pH above 4.0, part of the acid salts must be neutralized. Lime requirements for neutralization have been based on raising the pH to an approximate 7.0 or the neutral point. As the water-plant records do not give information directly on the daily quantities of chemical required for this purpose, it has been determined on the basis of long-time averages that Monongahela River water at McKeesport above the mouth of Youghiogheny River having a pH of 7.0 will have a methyl orange alkalinity of 14 parts per million and a phenolphthalein acidity of 5 parts per million. Similarly, Allegheny River water at the Pittsburgh intake at Aspinwall having a pH of 7.0 will also have a methyl red alkalinity of 14 parts per million. Neutralization costs were based on adding sufficient lime to bring the waters up to the alkalinities stated. On days when the alkalinity was above these values it was assumed that no lime was needed.

All of the original acid load as measured by phenolphthalein will be represented by noncarbonate hardness. That part of the acid load neutralized by natural alkalinity will convert carbonate hardness to noncarbonate hardness. That part of the acid load neutralized by lime will also convert the carbonate hardness added by the lime to noncarbonate hardness.

The mean parts per million total acid concentration as $CaCO_3$ was computed by applying the original acid loads as given in table Ac–2 to the average flow in the various streams. As explained, this acid will be represented by noncarbonate hardness and will require soda ash for removal in the domestic and boiler waters.

Steamboats and barges.—River-transport equipment suffers slight to severe damage as a result of corrosion of boilers, hulls, pipes, and pumping facilities. Besides corrosion difficulties, scale and sludge formation in boilers, with accompanying poor heat transfer and increased blow-down, and time out of service cause added operating difficulty and expense.

Managers of transportation companies were interviewed and asked for data on damages resulting from acid in the streams. This information was broken down into boiler replacements, boiler cleaning,

repairs to hulls, replacements of pumps and pipes, loss of revenue while out of service, and the maintenance of barges. Average cost per boat or barge for the above items was computed. The Pittsburgh office of the United States Engineer Department furnished information on the number of boats and barges operating in the district. The annual damages were then computed from the average figures and the numbers of vessels.

Power plants.—The quantities of cooling water used by power plants are very high and neutralization of this water is not practical. In general, water is used without neutralization and equipment is replaced when made necessary by corrosion.

Before making estimates of damages to power plants, many plant superintendents were interviewed and data obtained as to the frequency and cost of replacements and the portion attributable to corrosion. Consideration was given to such factors as average acidity of the water, type of metal used, length of service, time lost by shutdowns, and labor costs.

The power plants were grouped by localities and estimates made of damages per unit of capacity for each group. Total damages were then readily computed.

The fact that power plants practice repair and replacement of equipment rather than neutralization of acidity in cooling water is evidence that repair and replacement is the more economical procedure. As a check, the cost to power plants of neutralizing cooling water was computed on the same basis as was the cost to municipal and industrial water supply. Neutralization cost was found to be $261,000 per year as compared to $76,000 for repairs and replacements due to corrosion. This would confirm the wisdom of power plants in not attempting to neutralize cooling water.

River and harbor structures.—Acid pollution results in damage by corrosion to locks, dams, and other appurtenances. This corrosion is accelerated to some extent by the erosive action of the water, which keeps the exposed surfaces clean and damages protective coatings. Since the United States Engineer Department is responsible for the construction, operation, and maintenance of these structures, the officials concerned were interviewed and asked for an estimate of the annual damages. The figure is based mainly upon experience in regard to average frequency of repairs and replacements.

Floating plant (U. S. Engineer Department).—An estimate of damages to their floating plant was furnished by the United States Engineer Department.

Other damages.—Damages which are important but for which no detailed estimates have been made include (1) damage to water supply caused by the presence of manganese, (2) damage to recreation through the destruction of normal aquatic life, (3) damage to agricultural uses, (4) damage to highway structures, (5) damage to the mines themselves, and (6) the previously mentioned indeterminate but serious damage to the public health.

Manganese is present in acid-mine drainage streams but field investigations did not yield information indicating damage of great consequence. Sand filter plants remove the greater part of the manganese without special provisions.

Damage to recreation is an item of great consequence. The Allegheny Reservoir report of the United States Engineer Department estimates benefits to recreation from Allegheny Reservoir (reservoir

full elevation 1,365) equal to $300,000 per year due chiefly to the effect of this reservoir in reducing and eliminating the acidity. Neither the existence nor the magnitude of these benefits, which represent the correction of damages, can be denied but the various methods proposed for the evaluation of recreation facilities are all open to some question.

Damage to agricultural uses include destruction of a water supply used for stock watering or other purposes, damage to inundated land during high water, and damage due to destruction of crop-growing ability of land by seepage from a mine, as at an outcrop.

Considerable damage results yearly to bridges, culverts, drains, and other highway structures from the acid waters. State officials generally agree that acid-mine drainage causes considerable added expense each year, but no specific records are available. Replacements have been greatly reduced in recent years by building structures having stone or brick facing and by using a bituminous-coated pipe on streams carrying mine drainage.

Damage to the mines themselves is definitely a factor. There are instances of record of a mining company finding it necessary to go a matter of several miles for a satisfactory water supply at the same time that acid water was available in quantity from its mine. In one case, power was purchased even though usable but unmarketable coal was available. An almost universal source of damage is the corrosion of metal work, especially pumps and pipe lines connected with drainage system. A mine may well find it distinctly profitable to seal worked-out sections of its active mine in order to decrease damage to pumps, pipe lines, and other metal work and to provide an improved water supply. The savings in ventilation have been mentioned.

Some of these damages are capable of evaluation but either time has not been available or expenditures necessary have not been deemed justified. Other damages have not been evaluated either because of the lack of available long-range data or because of the indeterminate nature of the damage.

Although, as stated, no estimate has been made of the magnitude in dollars of the miscellaneous and intangible damages discussed, it may be reasonable to assume that these damages are probably equal to the tangible damages for which estimates have been made.

A clean or unpolluted stream is an extremely difficult item to evaluate. The value depends not only upon monetary considerations which can be estimated with a degree of accuracy but also upon the popular demand and the relative urgency of this demand as compared to other demands upon public and private funds.

An indication of the value of clean streams is shown in the actual expenditures in other areas for the correction of polluted conditions caused by sewage and organic wastes. State-wide averages for pollution-abatement programs on tributary streams have been in the neighborhood of from $25,000 to $75,000 per mile of stream improved. The variation depending upon the size of stream, magnitude of the pollution problems, and degree of treatment required. Costs on a main stream such as the Ohio River would be much higher than these figures.

Presentation of Laboratory Data

The presentation of the detailed laboratory data collected during the course of the Ohio River pollution survey is included in the individual drainage basin presentations to which they apply. These data define the extent of the acid mine drainage problem and show in terms of analytical results the effect of acid mine drainage on Ohio River Basin streams. Figures A–5b and Mo–5a taken from the main volume of the final report of the Ohio River pollution survey show the extent of acid mine drainage effects as indicated by pH results on stream-water samples on the Allegheny and Monongahela River Basins, respectively.

In addition to the routine sampling at all important points on the Ohio River Basin, a laboratory unit stationed at Morgantown, W. Va., from late in July 1940 to the end of June 1941 performed work relative to the effects of coal-mine acid on specific streams. This work is the subject of a separate, special report.

WATER-PLANT RECORDS

The raw-water analytical records collected over a period of years by the water plants using river water furnish a valuable source of material for a study of the increasing effect of acid mine drainage during the development of the coal-mining industry. With the help of these records, a general long-time trend can be established and estimates of future conditions can be made.

As was discussed earlier, if computations of annual average discharges of acid in tons are made, the effect of storage reservoirs that store and release water during the same year is eliminated. Accordingly, water-plant records were converted into annual average tons of acidity (or alkalinity) and the results plotted for the period of record. Figures Ac–10 and Ac–11 were prepared in this manner. Mass diagrams of total coal production were plotted on the same graph using a scale selected such that the resulting curve serves as a trend line for the acidity curve. On the Allegheny curve, figure Ac–10, sulfates are also plotted, since results of this determination were available. Mine-acid loads, with expected reductions by sealing, have been plotted on a parallel scale.

Discussion

This report has covered the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Estimates have been presented of the total acid load, the reduction in this load to date, and possible future economical reduction by mine sealing under 1940 restrictions. Costs of this program to date and estimates of future cost are given. Damages have been enumerated, discussed, and evaluated.

A consideration which should be mentioned early and kept in mind constantly is that the acid mine drainage problem has been constantly growing and there is little reason to believe that this growth will not continue. The acid mine drainage was no great problem in 1900 but by 1910 it had made itself felt. By 1920 the Kiskiminetas and Youghiogheny Rivers had been acid for some time and the average

quality of the Monongahela River above the Youghiogheny was soon to become acid. Since then the problem has become progressively worse and in the high-acid year of 1934, the Allegheny River barely missed becoming acid in average quality. By 1955, at the present rate, the Allegheny River may easily have an average acid quality during a normal year.

Damages caused by acid mine drainage have been evaluated for the period from 1930 to 1940. During the next decade, unless corrective measures are actively pursued, these damages will continue their trend upward as the natural alkalinity of the principal streams becomes exhausted. As shown on table Ac–3, an increase in damages estimated at 50 percent may be expected by 1960.

REMEDIAL PROGRAM

A primary purpose of the acid mine drainage study has been to secure basic data on which to base a comprehensive remedial program. The program, as presented, involves mine sealing and flow regulation from storage reservoirs. The program is not the ultimate possible as the mine sealing discussed goes only as far as permitted by 1940 restrictions. However, a large step is involved and upon its completion additional knowledge should be available in planning further corrective measures.

The studies indicate definitely that the Allegheny River can be brought back to substantially satisfactory condition and this might well be a first objective of a remedial program. Although less-detailed studies have been made, it appears likely that many of the headwater streams of the Youghiogheny and Monongahela Rivers can be returned to satisfactory conditions and might well also be included as first objectives.

The Monongahela River above the Youghiogheny River can be greatly improved but, without going somewhat further than the present restricted program, present indications are that it cannot be brought back to the extent possible on the Allegheny River. There are two reasons for this: First, the original acid intensity in tons per square mile as shown on table Ac–1 is about four times as great as on the Allegheny River, and second, the normal upland water alkalinity (about 10 parts per million) is much less than that on the Allegheny River Basin (about 25 parts per million). However, against this, the damages caused by acid in the Monongahela River are very high due to extensive use for navigation and water supply and the possible monetary benefits from improvement of the stream are correspondingly greater. Because of this factor, the Monongahela Basin, especially above the Youghiogheny River, is a particularly fitting area on which to concentrate first in carrying out more advanced mine sealing beyond 1940 restrictions.

With the Allegheny River, certain upland streams, and finally the Monongahela River above the Youghiogheny River in good condition, it is probable that the main Ohio River will return to satisfactory alkaline quality. Even partial correction of Monongahela River acid, when combined with a satisfactory Allegheny River, might accomplish this objective.

Restoration of the Monongahela River below the mouth of the Youghiogheny River will come much later as it will probably require a substantial alkalinity from above the Youghiogheny River.

Fig. A-5b

ALLEGHENY BASIN

pH RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Fig. Mo-5a

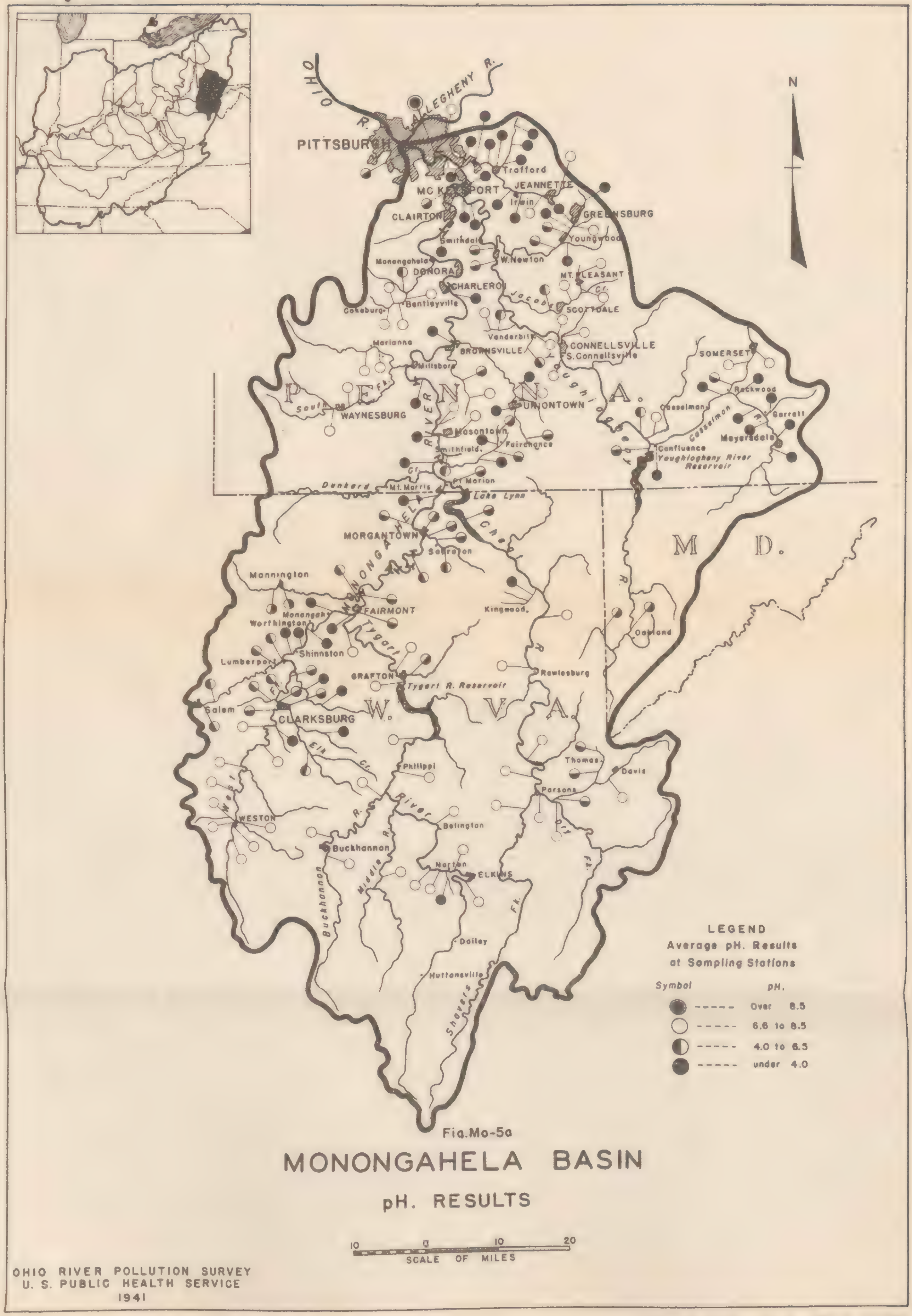


Fig. Mo-5a

MONONGAHELA BASIN

pH. RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

There remains the question of the Kiskiminetas and lower Youghiogheny Rivers, where present mining and the acid mine-drainage problems are concentrated. Much of the acid comes from active mines. This source is normally the last to be attacked and such attack must be confined to worked-out sections. It is probable that these two stream sections will not be completely returned to satisfactory quality until concentrated active mining moves, at least in part, to other areas.

In summary, it appears that the upper Ohio River and tributaries can best be returned to satisfactory alkaline quality in the following order:

(1) Allegheny River, except the Kiskiminetas River.
(2) Headwater streams, including the upper Youghiogheny.
(3) Monongahela River above the Youghiogheny River.
(4) Main Ohio River.
(5) Monongahela River below the Youghiogheny River.
(6) Lower Youghiogheny River.
(7) Kiskiminetas River.

The following discussions of the Allegheny and Monongahela Rivers cover a remedial program involving two types of corrective measures, namely, mine sealing and flow regulation. An estimate of the part each of these measures plays in the total improvement will depend upon which remedial measure is placed in operation first and the first measure will make the more impressive showing.

As a practical approach, the effects of the two remedial measures have been considered on a basis of monthly averages. One effect of reservoir operation will be to reduce or possibly eliminate day-to-day acid surges which create serious water-plant-operation problems and may render an otherwise satisfactory stream unfit for fish life. Flow-regulation benefits, in this respect, will not generally appear in a consideration of monthly averages. Thus one of the important features of flow regulation will not appear as a benefit. Considered from another standpoint, the benefits from mine sealing will be more fully realized if reservoirs for flow regulation are provided.

Conversely, the benefits from reservoir operation may depend, to a large extent, on mine sealing. The Tygart Dam, already mentioned, is an example where an acid stream was rendered alkaline, a reservoir was constructed and improvements resulted which no single remedial measure could have accomplished.

This discussion leads to a conclusion that if a complete program involving the two types of control measures is justified, the individual parts are justified. For this reason, acid-control benefits have been lumped in one figure. This means, in effect, that parts of the mine-sealing benefits, as computed from monthly averages, are assigned to flow regulation.

ALLEGHENY RIVER

Records are available on the quality of Allegheny River water at the intake of the Pittsburgh filter plant at Aspinwall from 1909 to date. Average annual alkalinity (to methyl red) and sulfate results in tons and cumulative coal production have been plotted on figure Ac–11. It is to be noted that the average annual results are subject to wide variations. Several times in the past there apparently have been periods of 4 or more years during which there has been a definite beneficial trend toward increased alkalinity. Each time there has

been a following adverse period so that the general long-time trend has been toward decreased alkalinity.

If the curve of cumulative coal production as shown on figure Ac–11 does, in fact, show the trend of alkalinity and sulfates, the natural alkalinity and sulfate content of Allegheny River water prior to the development of the coal industry were 1,400 and 1,000 tons per day respectively. The average flow of the Allegheny River at Aspinwall from 1909 to 1940, inclusive, was 20,400 cubic feet per second. Assuming equal distribution of alkalinity and sulfates in the average flow, a natural alkalinity of 25 parts per million and natural sulfate content of 18 parts per million are indicated.

The average alkalinity of Allegheny River water in 1909 actually was 25 parts per million. The lowest average annual sulfate result was 36 parts per million obtained in 1911, the first year of sulfate record. However, on several occasions average monthly sulfate results of 18 parts per million were obtained during the early years of record.

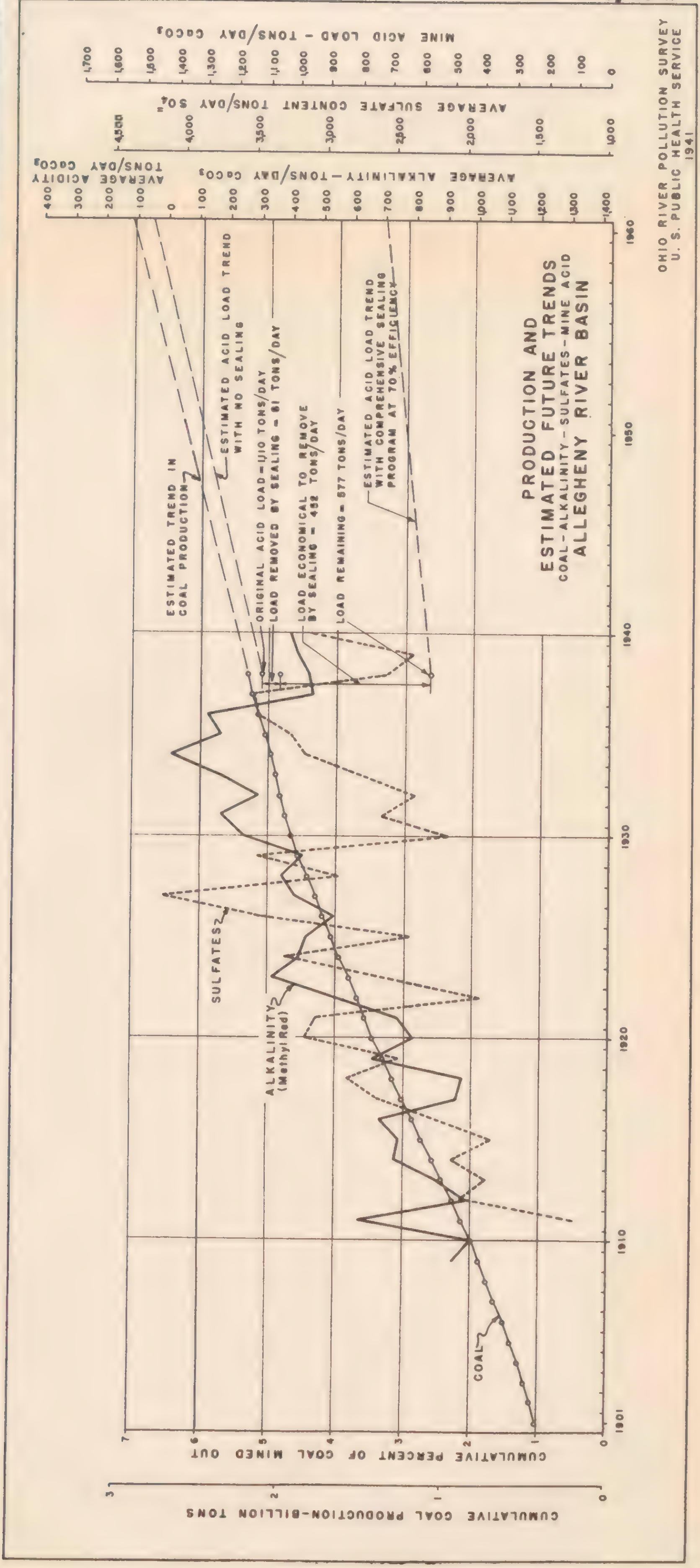
As compared to these old results, the Allegheny River at Aspinwall had an average acidity of 5 parts per million in 1934 although in tons, or a weighted average, as plotted on figure Ac–11, the average quality was alkaline. During that same year sulfates averaged 107 parts per million and on seven occasions the average annual sulfates have exceeded 90 parts per million.

There has been a definite downward trend or an increase in alkalinity since 1934. This year coincided closely with the start of mine-sealing activities. While part of the favorable trend may be due to mine-sealing activities, there is apparently an additional trend due to a normal cycle followed by the alkalinity curve. In 1934 the average annual alkalinity was 12 tons (to methyl red) per day and the 1940 average was 407 tons per day, an increase of 395 tons per day. Mine-sealing records indicate an acid reduction of only 81 tons (to phenolphthalein) per day which would not account for the great increase in alkalinity.

Mine sealing.—A principal purpose of plotting alkalinity, coal production, and estimated acid-load curves on parallel scales is to serve as a basis for estimating possible accomplishments by mine sealing. The coal-production curve appears to be a true-trend curve as it parallels lines drawn between successive peaks and successive low points and, in general, follows the course of the alkalinity curve. As the mine acid loads are plotted in parallel, it is not unreasonable to assume that completion of the mine-sealing program would drop the trend line to a line representing "estimated acid-load trend with comprehensive sealing program of 70 percent efficiency." The ordinate of this latter curve for 1940 approximates the ordinate of the coal production trend line for 1915. This would indicate that a comprehensive sealing program would return the Allegheny River to its 1915 condition.

If all mined-out areas that have developed since 1915 were, in some manner, eliminated as sources of acid pollution, it is to be expected that the acid mine drainage problem would revert to conditions as of that date. A comprehensive mine-sealing program is estimated to remove the influence of the equivalent of all mined-out areas developed since 1915. It is, therefore, reasonable to conclude that a comprehensive mine-sealing program would return the Allegheny River to its condition in 1915.

Fig. Ac-II



(Face p. 1018) GPO-43 O-90035

The maximum monthly acidity in the Allegheny River in recent years was 23 parts per million. This can be reduced in part by mine sealing and in part by a flow-regulation program. The estimated result of the combined program is a conversion of the maximum monthly acidity of 23 parts per million to a minimum monthly alkalinity of 13 parts per million or an improvement of 36 parts per million. On an equitable basis, mine sealing can be credited with an improvement of 22 parts per million in the maximum monthly acidity. Improvement in the average quality would be much less.

Reduction in the Allegheny River acid should result in a lesser but important reduction in Ohio River acidity.

Flow regulation.—The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity in the Allegheny River but there will still remain acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest-flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage.

A flow-regulation program is suggested involving storage in a reservoir or reservoirs of 210,000 acre-feet capacity. On an equitable basis, this flow regulation can be credited with a 14 parts per million improvement in the maximum monthly acidity, and a lesser improvement in the Ohio River. More stabilized flow will furnish partial protection against acid surges.

The Kiskiminetas River, entering the Allegheny River in its lower reaches, drains a concentrated mining area and is, therefore, nearly always acid. Local rains in the area result in serious acid discharges into the Allegheny River and local storage will be required to combat the damages by discharging alkaline water to neutralize the acid surge. Upland storage is of little value in this case as the damage would be done and the danger over by the time water from such storage arrived. Therefore, any reservoir program on the Allegheny River for acid control will require limited local supplementary storage, as behind a local navigation dam provided with proper regulating devices.

The objective and principal features in the operation of the flow-control program presented are as follows:

(1) The objective of the program is to maintain, as nearly as possible, a minimum alkalinity of 13 parts per million rather than secure the greatest monetary benefits from acid and hardness control. such an objective tends to protect aquatic life.

(2) Storage is assumed to take place only during months when the alkalinity at Aspinwall is above 13 parts per million.

(3) The quantity of water assumed to be stored is never such as to reduce the alkalinity at Aspinwall to a concentration below 13 parts per million.

(4) Unregulated flows are increased as necessary to increase the alkalinity to 13 parts per million up to a maximum of the average flow of the stream or 20,400 second-feet.

(5) No attempt is made to increase alkalinity during months when the flow is in excess of the average of 20,400 second-feet. However, no water is stored during such months as such a procedure would further decrease the low alkalinity.

(6) The reservoir or reservoirs are assumed to be emptied each year. This feature and limitation in the amount of water that can be stored under the above restrictions governs the reservoir capacity suggested.

MONONGAHELA RIVER

Records are available on the quality of Monongahela River water above the mouth of the Youghiogheny River at the intake of the McKeesport water plant from 1917 to date. Average annual acidity (or alkalinity) results in tons and cumulative coal production have been plotted on figure Ac–12. As noted on the Allegheny River curve, the average annual acid results are subject to wide variations. However, the general trend, especially prior to the last few years, has been toward an ever-increasing acidity.

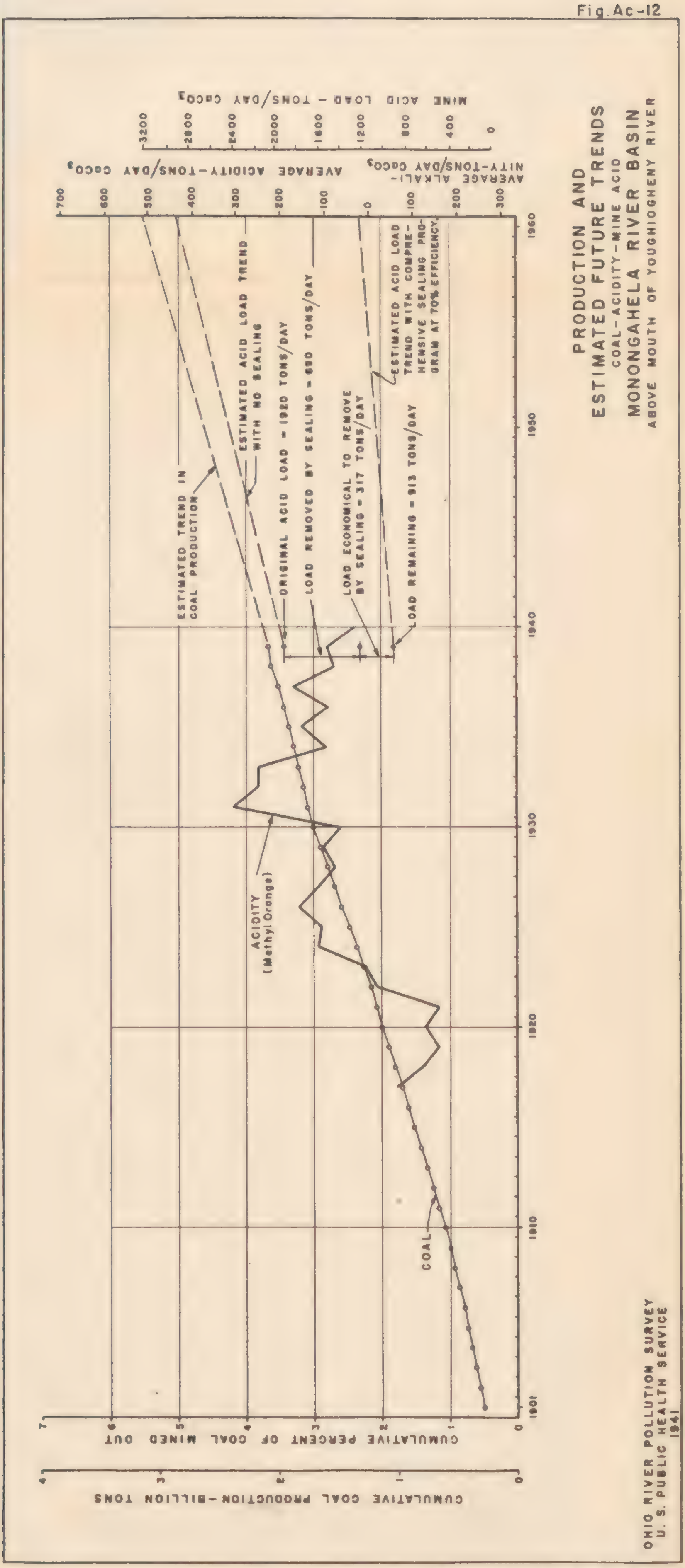
If the curve of cumulative coal production as shown on figure Ac–12 does, in fact, show the trend of acidity, the natural alkalinity of Monongahela River water prior to the discharge of acid mine drainage was 300 tons per day. The average flow of the Monongahela River above the Youghiogheny River from 1917 to 1940, inclusive, was 10,950 cubic feet per second. Assuming equal distribution of the alkalinity in the average flow, a natural alkalinity of 10 parts per million is indicated. During the early years of analytical record the Monongahela River above McKeesport was alkaline most of the time and as late as 1918 one monthly alkalinity of 8 parts per million was recorded.

As compared to this former quality, the Monongahela River above McKeesport had an average annual acidity of 16 parts per million in 1930, has had average annual acidities of 10 parts per million or more on nine occasions and has had an average quality acid to methyl orange every year since 1922.

During the past decade, or since 1931, there has been a marked decrease in the acid concentration of the Monongahela River. While most of the decrease has been during the comprehensive mine sealing program in the State of West Virginia, it has also been during a period of decreased mining activity, the construction of Tygart Dam and during a normal cycle as indicated by the corresponding Allegheny River curve. It is undoubtedly true that at least part of the favorable trend is due to mine-sealing activities. In 1931, the average annual acidity was 312 tons (to methyl orange) while in 1940 it was 33 tons per day, a reduction of 279 tons per day. Mine sealing records indicate an acid reduction of 690 tons per day but this is measured as phenolphthalein acidity.

Mine sealing.—As is the case of the Allegheny River, the curve on figure Ac–12 can serve as a basis for estimating possible accomplishments by mine sealing. As a comprehensive mine-sealing program is completed, it is assumed that the trend of acid discharge will leave the curve of cumulative coal production and drop to the line representing "estimated acid-load trend with comprehensive sealing program at 70-percent efficiency." There is evidence in the form of the curve that the trend of river-water quality, as shown on figure Ac–12, is already dropping to a line representing residual acid after sealing. However, this cannot be stated with positive assurance on the basis of water-plant records for a number of years. Assuming tentatively that the acid-trend curve will drop to a curve representing the residual

Fig. Ac-12



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acid load after sealing, it can be concluded that a comprehensive sealing program would return the Monongahela River above McKeesport to the condition it was in 1920. Consideration of the quantity of coal that has been mined out and the magnitude of the comprehensive mine-sealing program indicates that this conclusion is reasonable.

The maximum monthly acidity of the Monongahela River, above McKeesport, of 33 parts per million can be reduced by mine sealing and flow regulation to an estimated 4 parts per million. Of this 29-parts-per-million reduction of acidity, 19 parts per million can equitably be assigned to mine sealing. Improvement in average quality would be much less. A lesser improvement should also result in the Ohio River.

Flow regulation.—As in the case of the Allegheny River additional improvement is possible by the use of flow regulation from reservoir storage. It is estimated that the use of reservoir capacity totaling 370,000 acre-feet can accomplish a reduction in the maximum monthly acidity equitably estimated at 10 parts per million.

Objectives and methods of operation are the same as described for the Allegheny River Basin except that flow is increased only up to the average flow of 10,950 second-feet.

BENEFITS AND COSTS

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela, and upper Ohio River Basins due to the suggested mine-sealing and flow-regulation programs total $1,133,000 per year. That this estimate is conservative is indicated by the following considerations:

(1) The estimate is based on 1940 damages, whereas table Ac–3 (p. 984) indicates that estimated damages may increase 50 percent in the next 20 years.

(2) The estimate is based on a program of mine sealing under 1940 restrictions. A more complete sealing program could reduce the residual acid load an estimated further 50 percent and should yield much greater benefits. Costs would be higher but not in proportion to the increased benefits.

(3) The estimate does not include benefits to (*a*) decreased manganese in water supplies, (*b*) recreation, (*c*) agricultural uses, (*d*) highway structures, (*e*) the mines themselves, or (*f*) indeterminate benefits to the public health. These damages might reasonably be considered to equal the estimated monetary damages.

The estimated cost of the restricted mine-sealing program considered is $3,250,000. Annual charges of interest (3½ percent), amortization (0.7 or 3½ percent for 50 years), inspections (2 percent), and maintenance (7 to 10 percent) are about 15 percent, or $488,000 on this additional expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000, making a total cost of $870,000 per year. As shown on figure Ac–3 (p. 979) if these existing seals are not maintained, the benefits already realized may easily be lost, making it necessary to repeat the expenditure.

If the remedial program is considered as a whole, this annual cost deducted from the total benefits would leave $263,000 for expenditures for flow regulation. While this allocation of benefits is not unreason-

able, it probably does not do full justice to mine sealing which, if taken alone, will amply justify itself from a monetary-benefit standpoint.

Additional benefits because of organic pollution abatement are also available to flow regulation.

ORGANIC POLLUTION ABATEMENT

Organic pollution in the upper main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic-pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 cubic feet per second during the warm summer months (25° C. or 77° F. average monthly air temperature) and lesser flows during the colder months. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drought occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drought. A valuable partial organic pollution control would be available even during a year such as 1930.

Without flow regulation a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is $300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional $300,000.

While the flow regulation is designed primarily for acid-pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a valuable aid in organic-pollution control. The two flow-regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic-pollution control. An examination of flow and acidity records indicates that acid control and organic-pollution abatement can both be accomplished with the exception of 1 month (also excepting 1930) in 10 years and this accomplishment has been taken as satisfactory.

Storage required for organic-pollution abatement is 430,000 acre-feet (except in 1930) while flow required for acid control is 210,000 acre-feet in the Allegheny River Basin and 370,000 acre-feet in the Monongahela River Basin or a total of 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Annual benefits to flow regulation include $263,000 left after deducting mine-sealing costs from acid- and hardness-control benefits, plus $300,000 for organic-pollution control at Pittsburgh and $300,000 for organic-pollution control benefits at Cincinnati, making a total of $863,000 per year. As the storage required is 570,000 acre-feet, the annual benefits computed are about $1.49 per acre-foot.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

The essential features of the acid- and organic-pollution control program on the upper Ohio River Basin is shown in the Summary for Main Report which is also included in the first part of this supplement.

Personnel

The acid mine drainage studies, with the exception of laboratory activities, were carried out under the administrative direction of Sanitary Engineer Director H. R. Crohurst,[1] in charge of the Office of Stream Sanitation. The work was organized and carried out under the general direction of Sanitary Engineer Ellis S. Tisdale (reserve) and under the immediate supervision of Senior Public Health Engineer M. LeBosquet, Jr. A field office was established in the Office of Mine Sealing of the United States Public Health Service, Regional Consultant E. W. Lyon in charge. This field office for the Ohio River pollution survey was placed in charge of Assistant Sanitary Engineer Paul D. Haney (reserve). Assistant Sanitary Engineer Ralph C. Palange (reserve) and Assistant Chemical Engineer Royal E. Rostenbach were assigned to assist in the work.

Laboratory activities were performed under the administrative direction of Sanitary Engineer Director J. K. Hoskins, in charge of the Stream Pollution Investigations Station, succeeded in July 1940 by Medical Director H. E. Hasseltine. Technical direction of the work was by Sanitary Engineer Director H. W. Streeter. Passed Assistant Sanitary Engineer C. L. Chapman (reserve) was in charge of special acid-stream work at Morgantown, W. Va.

Estimates of accomplishments and financial benefits of acid-control measures were prepared in the Cincinnati office, and the final supplement C is the joint work of Messrs. LeBosquet and Haney with assistance in the preparation of estimates by Mr. Palange.

The supplement was reviewed by Mr. Lyon, R. D. Leitch, chemical engineer of the Bureau of Mines, Pennsylvania officials, and others. Valuable contributions were made in these reviews.

[1] Deceased.

SUPPLEMENT D

INDUSTRIAL WASTE GUIDES

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INDUSTRIAL WASTE GUIDES

INDUSTRIAL WASTE GUIDES

Survey Authorization

The Ohio River pollution survey, recently completed, was authorized by the Congress to cover the Ohio River and its tributaries, with the specific instructions:

(1) "* * * to ascertain what pollutive substances are being deposited * * *" and

(2) to make the survey "* * * with a view of determining the most feasible method of correcting and eliminating the pollution * * *"

In considering industrial wastes, these instructions have required, first, a determination or estimate of the strength and quantity of each industrial discharge and, second, a determination of indicated treatment or other corrective measures with estimate of cost to apply to each of these discharges. With a total of 1,800 waste-producing industrial plants in the basin, the assignment has been a work of considerable magnitude.

Description of Guides

An essential step in the work has been the preparation of the industrial waste guides, which summarize information available on pollution problems connected with the various classes of industrial establishments found in the Ohio River Basin. Characteristic features of the guides, which are all prepared along similar lines, include—

(1) An Abstract, giving, in brief form, the essential features of the guide.

(2) Description of Process, covering the various principal operations in the industry.

(3) Raw Materials and Products, enumerating these items and giving quantity relationships including number of employees.

(4) Sources and Quantities of Wastes, discussing waste-producing operations and estimating quantities from individual processes and the total industry.

(5) Character of Wastes, presenting analytical results of individual process wastes and the total composite wastes, and discussing important characteristics of each waste.

(6) Pollution Effects, discussing principal objections to discharge of each waste to streams.

(7) Remedial Measures, discussing corrective measures involving steps within the plant such as recovery practice and disposal of waste materials other than to the sewer, as well as treatment practiced or in various stages of development. Cost data, when reliable, are included in some cases.

(8) Bibliography.

(9) Note-taking Form, as used in the field in collecting data from industrial plants.

(10) Inspection Report, such as is prepared by the field engineer from the data on the note-taking form and other notes.

(11) Flow Diagrams, illustrating in diagrammatic form the industrial process steps, waste flows, and recovery practices.

The 11 industrial waste guides presented cover the principal types of industries found in the Ohio River Basin. Steel mills which contribute acid pickle liquors, certain chemical plants which contribute acid and organic materials, plastic and synthetic fiber manufacturing plants, and textile plants other than cotton are notable exceptions. Information has been collected on the wastes from these classes of industry but wide variations which make each plant unique, or time limitations, have prevented presentation of this information in the form of guides. Other industries generally mentioned in industrial waste discussions are not common to the Ohio River Basin.

Uses of Guides

The industrial waste guides have been of great assistance in the industrial waste activities of the Ohio River Pollution Survey, both along lines originally intended and along lines that later developed during the course of the work. Some of the more important uses are as follows:

(1) Assistance to field engineers.

(2) Assistance in estimating strength, volume, and sewered population equivalents of industrial discharges.

(3) Assistance in determining indicated remedial measures and costs.

(4) Assistance in soliciting unpublished information from engineers, chemists, and others familiar with specific industrial wastes.

Sources of Information

Basic information on industrial wastes, including remedial measures, has been obtained from (1) the published literature; (2) private communications with engineers and chemists, municipal and private, equipment manufacturers, industrial management, trade associations, and others; (3) sampling and gaging results obtained in connection with the present survey; (4) field engineers' reports on routine inspections in connection with the present survey; and (5) United States Public Health Service files.

The review of published information has been largely confined to American publications, and European and other foreign practices are incorporated, with few exceptions, only insofar as it is reported in American literature. Important references are listed in the bibliographies of the individual guides.

Excellent cooperation and valuable information have been received through private communications from municipal and private engineers and chemists, equipment manufacturers, industrial management, trade associations, and others. This information has been received as a result of written inquiry and consultation. The industrial waste

guides were first issued in limited number in preliminary form and distributed to those familiar with specific industries. Comments, corrections, and supplementary information received in reply have been particularly valuable. Results of sampling and gaging studies made by the Sanitary District of Chicago are worthy of special mention.

Detailed information on representative industrial plants has been secured during the present survey by cooperative arrangements with the Tennessee Valley Authority, the State of West Virginia, and the cities of Louisville, Ky., and Cincinnati, Ohio. Programs were coordinated and assistance was furnished in the cases of the Tennessee Valley Authority, the State of West Virginia, and city of Louisville. Sampling and gaging studies were made at a total of 29 industries, of which 15 were in the Tennessee Valley, 3 in the State of West Virginia, and 11 in and near the city of Louisville. Particular attention was devoted to securing information on individual discharges rather than confining activities to the total plant wastes. In the cases of Louisville and Cincinnati, rather extensive surveys were made by these cities for the purpose of designing sewage collection and treatment works for the abatement of pollution. In the case of Cincinnati, individual industries were not as a rule studied, but comprehensive sampling and gaging studies were made on all sewer outfalls, making it unnecessary for the Ohio River Pollution Survey to cover the industries individually.

Some of the best available sources of information on remedial measures now in practice are the reports of routine inspections made in connection with the Ohio River Pollution Survey. As shown on table 2, slightly over half the industrial plants not now discharging to municipal treatment plants have already taken at least minor corrective measures to abate pollution. The detailed data has been of considerable assistance in determining indicated remedial measures, as many of the outstanding instances of industrial waste treatment are located in the Ohio River Basin.

As a result of the previous Ohio River survey and of other studies, the Cincinnati files of the United States Public Health Service contain additional information on industrial wastes, particularly on the subject of strength and quantity factors.

Survey Methods

The standard procedure followed in the survey of industrial waste discharges has been by inspection and report, using a classified industry (I–1 to I–12) or the miscellaneous (I–M) "note-taking form" and the standard form of report shown at the back of each industrial waste guide.

At plants that are unique, or which, by reason of products or processes could not be compared with others, it was necessary to collect samples for examination and to measure or estimate flows. Samples of individual discharges were collected at the point of creation of the waste in a number of instances. Accurate information is usually available on quantities of such discharges which are often intermittent, whereas sampling of total plant discharges diluted by cooling and other waters would necessitate careful, long-time gaging and composite sampling.

Sampling and gaging studies over periods of from 2 to 10 days were carried out at a number of typical as well as unique industries. Special effort was made to select industries willing to furnish detailed operating data covering the period of study, so that gaging and analytical results could be correlated with plant operations.

Sewered Population Equivalents

Industrial wastes may be objectionable for a great variety of reasons. They may contain—

(1) High organic or biochemical oxygen demand content.
(2) Suspended solids.
(3) Chemicals toxic to aquatic life.
(4) Excess acid, hardness, or salinity.
(5) Taste- and odor-producing substances.
(6) Undesirable coloring matter.

Although no single measure of pollution is applicable to all of these types of industrial wastes the biochemical oxygen demand is the most nearly satisfactory. Sewered population equivalents of industrial wastes have been based on 0.167 pounds of 5-day, 20° C. biochemical oxygen demand per capita per day.

In a few cases, sewered population equivalents based on suspended solids have been considered. Such an equivalent is of interest at industrial plants discharging or planned for discharge to municipal treatment plants, particularly of the plain sedimentation type where sludge quantities are important. Per capita contribution of suspended solids has been taken as 0.2 pound per day.

A summary of the typical sewered population equivalent (biochemical oxygen demand) figures based on units of production is shown in table 1.

TABLE 1.—*Summary of waste discharges, sewered population equivalents, and employees per unit of production, with typical analytical results, for various industrial wastes*

Industry	Unit of daily production	Employees per unit	Wastes, gallons per unit	Typical analyses, parts per million		Sewered population equivalents [1]		Remarks
				Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids	
Brewing	1 barrel of beer	0.25	470	1,200	650	19	9	Spent grain dewatered.
Do	do	.25	470	800	450	12	6	Spent grain sold wet.
Canning:								
Apricots	100 cases No. 2 cans		8,000	1,020		410		
Asparagus	do		7,000	100	30	35	9	
Beans:								
Green	do		3,500	200	60	35	9	
Lima	do		25,000	190	420	240	440	
Pork and	do		3,500	920	225	160	33	
Beets	do		3,700	2,600	1,530	480	240	
Corn:								
Cream style	do	45	2,500	620	300	75	30	
Whole kernel	do		2,500	2,000	1,250	250	130	
Grapefruit:								
Juice	do		500	[2] 310	[2] 170	[2] 8	[2] 3	
Sections	do		5,600	1,850	270	520	63	
Peaches, pears	100 cases cans		6,500	1,310		440		Size of can unknown.
Peas	100 cases No. 2 cans	1	2,500	1,700	400	210	40	
Pumpkin (squash)	100 cases No. 2½ cans		2,500	6,400	1,850	800	190	
Sauerkraut	100 cases No. 2 cans		300	6,300	630	100	8	
Spinach	do		16,000	620		490		
Succotash	do		12,500	520	250	330	130	
Tomatoes:								
Products	do		7,000	1,000	500	350	150	
Whole	do	6.5	750	4,000	2,000	150	60	
Coal washery	1,000 tons coal washed	6		15	115,000			
Coke	100 tons of coal carbonized	8	360,000	85		1,500		Wastes cause tastes and odors.
Distilling, grain:								
Combined wastes	1,000 bushels grain mashed	40	600,000	230	360	3,500	2,300	Excluding intentionally discharged slop.
Thin slop	do			34,000		55,000		
Tailings	do			740		50		
Evaporator condensate	do			1,200		1,500		
Distilling, molasses	1,000 gallons 100 proof	8	8,400	33,000	3,270	12,000	1,000	Molasses slop.
Cooling water	do		120,000					

[1] Persons per unit of daily production.
[2] Excluding peel bin wastes.

TABLE 1.—*Summary of waste discharges, sewered population equivalents, and employees per unit of production, with typical analytical results, for various industrial wastes*—Continued

Industry	Unit of daily production	Employees per unit	Wastes, gallons per unit	Typical analyses, parts per million		Sewered population equivalents		Remarks
				Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids	
Meat:								
Packing house	100 hog units of kill	30	550			[3] 77	[3] 25	
Do	do	30	550	900	650	24	14	1 cattle equals 2½ hog units = 2½ calves = 2½ sheep.
Slaughterhouse	do	20	160	2,200	930	18	6	
Stockyards	1 acre		25,000	65	175	80	180	
Poultry	1,000 pounds live weight	6	2,200			300	160	Average weight=4.5 pounds per animal.
Milk:								
Receiving station	1,000 pounds raw milk and cream.	.15	180	500		4	2	
Bottling works	do	.89	250			6	3	
Cheese factory	do	.38	200	100	750	16	9	
Creamery	do	.16	110	1,250	660	6	3	
Condensery	do	.47	[4] 150	1,300	750	7	4	
Dry milk	do	.39	150	480		6	3	
General dairy	do	1.09	340	570	540	10	5	
Oil field	100 barrels crude oil	1.3	18,000					
Oil refining	do	3	77,000	20	50	60	120	1 barrel=42 gallons.
Paper:								
Paper mill	1 ton of paper	4.4	39,000	19	452	26	520	No bleaching.
Do	do	4.6	47,000	24	156	40	220	With bleaching.
Pasteboard	do	2.1	14,000	121	660	97	415	
Strawboard	do	1.4	26,000	965	1,790	1,230	1,920	
Deinking	do		83,000	300		1,250		Old paper stock.
Paper pulp:								
Ground wood	1 ton dry pulp	2.5	5,000	645		16		
Soda	do	3.0	85,000	110	1,720	460	6,100	
Sulfate (kraft)	do		64,000	123		390		
Sulfite	do	3.1	60,000	443		1,330		
Tanning:								
Vegetable	100 pounds raw hides	7	800	1,200	2,400	48	80	
Chrome	do					24	40	
Textile:								
Cotton:								
Sizing	1,000 pounds goods processed		60	820		2		
Desizing	do		1,100	1,750		96		
Kiering	do		1,700	1,210		108		

Bleaching	do		1,200	300		17		
Souring	do		3,400	72		12		
Mercerizing	do		30,000	55		83		
Dyeing:								
Basic	do		18,000	100		100		
Direct	do		6,400	220		71		
Vat	do		19,000	140		130		
Sulfur	do		5,400	1,300		360		
Developed	do		14,400	170		120		
Naphthol	do		4,800	250		59		
Aniline black	do		15,600	55		41		
Print works	do		4,500	95		15		
Finishing	do		6	1,250		0.4		
Rayon manufacture	1 cord wood distilled	35	680,000	30		1,000		Wood-distillation process.
Do	1,000 pounds rayon produced	64	160	4.4	19	35	130	Cupra-ammonia process.
Do	do	50	140	110	96	800	580	Viscose process.
Rayon hosiery	1,000 pounds hose produced		9,000	330		150		Boil-off and dye wastes.
Silk hosiery	do		13,700	1,720		1,180		Boil-off, dye, and finish wastes.
Woolen mill	1,000 pounds finished goods		70,000	111		400		Scouring and dyeing—no-grease wool.
Do	do		240,000	125		1,500		Scouring and dying—100-percent grease wool.

[3] Paunch manure to sewer.
[4] Excluding vacuum pan water.

Remedial Measures

Reduction of industrial-waste pollution is generally accomplished by one or more of the following measures:

(1) *Changes within the plant itself.*—This may involve reuse of all or part of the waste within the plant, development of byproducts, changes in plant processes, or merely greater care in plant operation to reduce the amount of material discharged as waste.

(2) *Treatment with municipal sewage.*—Many industrial wastes can be quite effectively treated in this way. It is often necessary to pretreat the waste at the sources or to segregate certain portions of the wastes within the plant and exclude those from the municipal sewers to prevent damage to sewerage structures or sewage-treatment processes.

(3) *Treatment in a special industrial-waste-treatment plant.*—For many types of wastes, such plants employ essentially the same processes as sewage-treatment plants. Other types of waste require specially developed processes. Most of the plants use the principle of sedimentation for removal of settleable solids.

The first method is usually the most economical and is one of those generally applied. It is occasionally possible to completely eliminate pollution and to recover valuable byproducts, but this is not the usual situation. Ordinarily some pollution remains and some expense is involved. The second method is simplest from the standpoint of the industry. It is also the most satisfactory from the standpoint of administration of pollution-abatement programs, and it reduces the number of possible sources of pollution and concentrates responsibility for effective waste treatment. It is usually necessary to make special provisions in the design of a municipal sewage-treatment plant if an appreciable amount of industrial waste is to be treated. Subsequent changes in the industrial-waste load sometimes cause difficulties.

The third method, treatment in a special industrial-waste-treatment plant, is used when the first is insufficient and the second impracticable. Segregation of cooling and other inoffensive waters for separate disposal is almost universal practice in attacking industrial-waste pollution problems. Likewise, separate collection of highly offensive concentrated materials or wastes for special attention, utilization, or recovery will often accomplish reduction in pollution at great savings over treatment costs.

In the industrial-waste-treatment field, chemical precipitation is popular, due largely to its ability to operate unaffected by greatly varying loads and toxic materials and to its lesser capital cost in comparison to biological processes. In those cases where removal of settleable solids is sufficient, the problem is not difficult, but satisfactory methods for the relatively complete removal of biochemical oxygen demand are available for only a few of the more common types of wastes, such as those from breweries, meat plants, milk plants, and some types of canneries and distilleries. There is a pressing need for the development of more efficient and economical methods for relatively complete treatment of other types of wastes. These problems are discussed in more detail in the individual industrial-waste guides.

Survey Results

The results of industrial-waste activities are presented in the individual tributary basin summaries of the final report of the Ohio River pollution survey. The magnitude of the problem of organic industrial waste is reflected in the sewered population equivalent figures. Wastes objectionable because of acid, salts, taste-producing, or other characteristics are covered in discussion. Table 2 of this supplement is a repetition of table 3 of the report proper, and summarizes data on the industrial-waste pollution load of nearly 10,000,000 sewered population equivalent found in the Ohio River Basin

Figure 1 is a repetition of figure 12 of the report proper and shows the location of plants by industries where corrective measures are indicated. Inasmuch as the wastes from many industrial plants are now handled in a satisfactory manner, the figure does not show all plants but it indicates the areas in which industries of specific types are found.

TABLE 2.—*Ohio River Basin: Summary showing industrial wastes not discharging to municipal-treatment plants, suggested industrial-waste discharges to municipal treatment plants, and total of entire industrial-waste load in the basin*

Industry [1]	Number of plants	Industrial-waste disposal		At least minor corrective measures taken	Estimated sewered population equivalent (biochemical oxygen demand)	Suggested to municipal treatment	
		Municipal sewers	Private outlets			Number of plants	Population equivalent (biochemical oxygen demand)
Brewing	38	35	3	27	264, 300	37	263, 800
Byproduct coke	23	2	21	17	745, 200	2	24, 300
Canning	218	52	166	160	758, 900	64	310, 300
Chemical	65	10	55	36	1, 880, 400	8	138, 000
Distilling	67	14	53	53	1, 009, 700	20	624, 600
Meat	173	76	97	115	385, 700	123	323, 900
Milk	253	130	123	107	85, 100	167	74, 700
Oil refining	47	4	43	44	116, 500	2	15, 100
Paper	59	12	47	46	1, 659, 200	5	31, 500
Steel	174	15	159	71	(2)	12	0
Tanning	32	5	27	13	269, 600	13	55, 400
Textile	122	57	65	10	335, 100	84	216, 900
Miscellaneous	333	104	229	109	160, 300	89	132, 500
Total	1, 604	516	1, 088	808	7, 670, 000	626	2, 211, 000
Industrial wastes to Cincinnati sewers [3]					1, 108, 400		1, 108, 400
Wastes discharged to municipal treatment					1, 195, 900		
Totals for the basin					9, 974, 300	626	3, 319, 400

[1] Industries occurring only once in a basin are included under "Miscellaneous" in the basin summary but are under their proper classification in this table.
[2] 336,000 pounds free acid discharged daily in waste pickle liquor.
[3] Industries not surveyed individually. Population equivalent based on comprehensive sewer gaging and sampling program of city.

Acknowledgments

The compilation of industrial waste information and the preparation of the industrial-waste guides were carried out with the collaboration and assistance of numerous State officials, engineers, and chemists representing municipal and private interests, equipment manufacturers, industrial management, trade associations and others. Special mention is made of the Tennessee Valley Authority, the State

of West Virginia, and the cities of Louisville and Cincinnati, who cooperated and assisted in sampling and gaging studies of industrial wastes, or made the results of such studies available. Dr. F. W. Mohlman, of the Sanitary District of Chicago, contributed results of sampling and gaging studies of that organization.

While it is not practicable to mention here all sources of information, the bibliographies of the individual guides present comprehensive listings of information sources. The National Canners' Association, the State of Wisconsin, and Mr. A. E. Kimberly furnished valuable information used in the cannery guide. Mr. H. A. Trebler, of Sealtest, Inc., and Mr. R. O. Henszey, of the Carnation Co., furnished information for the milk guide. Mr. W. B. Hart, of the Atlantic Refining Co., furnished information for the oil guide. Mr. C. M. Baker furnished information for the paper guide. Officials of the States of West Virginia and Pennsylvania, and Mr. Fred O'Flaherty, of the Tanners' Council of America, furnished information for the tannery guide.

Personnel [1]

The personnel of the Ohio River Pollution Survey contributing to the compilation of information on industrial-waste pollution and the preparation of the Industrial Wastes Guides are as follows:

H. R. Crohurst,[2] sanitary engineer director, administrative direction.

Ellis S. Tisdale, sanitary engineer (reserve), technical direction.

M. LeBosquet, Jr., senior public health engineer, immediate supervision of industrial-waste activities and editing of all guides and revisions; prepared drafts of Brewery, Distillery (coauthor) and Cannery (tomato, coauthor) Guides, and prepared revisions of Coal Washery, Coke, Cotton, and Distillery Guides for final report.

Samuel R. Weibel, associate public health engineer, compiled the bulk of industrial waste information, assisted Mr. LeBosquet and prepared drafts of Meat, Milk, Oil, Paper (and Paper Pulp) and Tannery Guides.

William T. Eiffert, assistant public health engineer, assisted Mr. Weibel and Mr. LeBosquet during 1940–41.

Gordon E. McCallum, associate public health engineer, prepared drafts of Cannery (corn, tomato-coauthor, and peas) Guide.

George D. Reed, assistant public health engineer, prepared drafts of Distillery (coauthor) and Coal Washery Guides, and supervised, for the United States Public Health Service, the cooperative sampling and gaging studies with the city of Louisville.

H. Gardner Bourne, Jr., assistant chemical engineer, prepared draft of Coke Guide, and assisted, for the United States Public Health Service, in cooperative studies with the State of West Virginia.

Ralph Porges, assistant sanitary engineer (reserve), prepared draft of Cotton Textile Guide.

Richard F. Poston, associate public health engineer, supervised, for the United States Public Health Service, the cooperative sampling and gaging studies with the Tennessee Valley Authority.

Richard L. Woodward, associate public health engineer, prepared revisions of Brewery, Cannery, Meat, Oil and Tannery Guides for final report.

Ralph C. Palange, assistant sanitary engineer (reserve) prepared revisions of Milk and Paper Guides for final report.

[1] Official designations apply to the last day of each person's connection with the Ohio River pollution survey.

[2] Deceased.

Fig.-1

OHIO RIVER BASIN

SUGGESTED INDUSTRIAL WASTE CORRECTION

NOTE:– Exclusive of plants where present corrective measures are adequate

25 0 25 50 75 100 125 150 175 200
SCALE OF MILES

OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

APPENDIX I OF SUPPLEMENT D

BREWERY

An Industrial Waste Guide to the Brewery Industry

CONTENTS

Abstract

Beer is produced by the fermentation of substances extracted from a mixture of malt, other prepared cereals, and hops. The wastes from brewing include large amounts of cooling water; wash water used in cleaning bottles, kegs, floors, and equipment; drainage from the spent grains, hops, and yeast. The spent grains and hops are disposed of separately, the grain having a considerable market value as cattle feed. The strongest wastes are the yeast and water extracted from the spent grain. Many breweries, particularly the smaller ones, sell the grain in a wet condition thereby eliminating an appreciable pollution load.

Although the waste flow per unit of product varies considerably, 300 gallons per barrel is a reasonably representative figure for breweries having to buy water and pay for waste disposal. The biochemical oxygen demand of wastes at plants where the grain is dewatered is approximately 1,200 parts per million and suspended solids 650 parts per million. If the grain is sold wet the biochemical oxygen demand is approximately 800 parts per million and suspended solids about 450 parts per million. The following sewered population equivalents are indicated:

	Sewered population equivalent [1] per barrel of beer per day	
	Grain dewatered	Grain sold wet
Biochemical oxygen demand	19	12
Suspended solids	9	6

[1] Based on per capita discharge of 0.167 pound of 5-day, 20° C. biochemical oxygen demand and 0.2 pound of suspended solids per day.

Brewery wastes can be treated effectively on trickling filters. Chemical precipitation has shown fairly good results on an experimental scale but the cost was relatively high. The only brewery waste-treatment plant known which uses activated sludge has not yet shown consistent results. Most breweries are so located that their wastes can be most satisfactorily disposed of with municipal sewage. If proper provision is made in sewage-treatment plant design, treatment with sewage can usually be accomplished without detriment to the municipal treatment plant.

Description of Process

Beer is an effervescent beverage resulting from the thorough alcoholic fermentation of a hopped solution, in potable water, of the extractive substances principally of barley malt, together with, if desired, other prepared cereals or their natural equivalents. Although many kinds of beer are made the processes in common use in this country today are fairly well standardized.

The barley malt is usually purchased by the brewery. (Malting establishments are concentrated in or near the barley-producing areas in Wisconsin, Minnesota, and other North Central States.) The malt is mashed by subjecting it to the action of water with heating and stirring to extract the desired substances, by effecting the inversion of the starch into maltose, malto-dextrin, and dextrin, and by the modification of some of the insoluble albuminoids into soluble ones. The enzymes, diastase, and peptase in the malt are the agents which bring about these changes. The unmalted cereals (usually rice and corn) are added during mashing. After the mashing has been completed the mixture in the mash tub is allowed to settle after which the extract, the wort, is drawn off through the settled solids. These solids are then sprayed with hot water (sparching) to recover additional wort. The wort is boiled, hops added, and the boiling continued. The boiling helps to clarify the wort and to remove certain undesirable constituents. The wort then goes to the hop back where the spent hops are removed. It is cooled and aerated, yeast added, and the mixture allowed to ferment. When the fermentation is completed, the beer is cooled again and stored in cellars where a low temperature is maintained for aging. When sufficiently matured it is clarified and carbonated. The beer is then ready for packaging in kegs or bottles.

Raw Materials and Products

RAW MATERIALS

(*a*) Malt, about 36 pounds per barrel (31 gallons) of beer. The average quantity of malt used by 35 breweries in the Ohio Basin was 34 pounds per barrel and varied from 25 to 44 pounds per barrel.

(*b*) Unmalted cereals, usually corn or rice grits, but occasionally other cereals such as wheat or rye. Cereal sugars or sirups also are used, particularly corn sirup. One plant in the Ohio Basin used soybean meal. About 14 pounds of these materials are used per barrel of beer. The average quantity of unmalted cereals and sirups used by 35 breweries in the Ohio Basin was 12 pounds per barrel and this varied from 8 to 18 pounds per barrel.

(*c*) Hops or hops extract, about 0.6 pound per barrel of beer. The average quantity of hops used by 34 breweries in the Ohio Basin was 0.6 pound per barrel and varied from 0.4 to 1 pound per barrel.

(*d*) Yeast, about 1 pound per barrel.

PRODUCTS

The standard unit of production of beer is the barrel, containing 31 United States gallons. The total national production for the year ending June 30, 1940, was 54,891,737 barrels. Six hundred and eleven breweries were in operation during that year. Forty-four breweries surveyed in connection with the Ohio River pollution survey produced about 4,150,000 barrels per year. The smallest ones produce about 10,000 barrels and the largest ones more than 500,000 barrels per year. About half of the beer sold is in bottles and the other half is sold as keg beer. The increase in the amount of beer bottled has been marked in recent years.

EMPLOYEES

The number of employees per unit of production varies greatly. The average of 44 plants in the Ohio Basin was 1,090 barrels per plant employee per year but this figure varied from 340 to 2,130 barrels. In some instances these variations are due to the inclusion of employees of ice plants or soft-drink bottling plants operated in conjunction with the brewery. In others, little or no bottling is done with a corresponding increase in beer production per employee. More than half of the breweries surveyed showed productions per employee of between 700 and 1,400 barrels per year.

Sources and Quantity of Wastes

The average amount of wastes from 23 breweries in the Ohio Basin on which reasonably accurate data were available was 170 gallons per barrel of beer. Two plants which bought all water from public supplies used less than 200 gallons per barrel whereas several which had private wells for at least part of their supply used more than 700 gallons per barrel. In a few instances water usage in excess of 1,000 gallons per barrel were reported but since these figures were of doubtful accuracy they were not included in the above average although these high figures

are not improbable. The principal cause of these variations is a variation in the amount of cooling water used. Mohlman found the average waste flow from 28 Chicago breweries to be 320 gallons per barrel, varying from 180 gallons in winter to 500 gallons in summer. A Houston, Tex., brewery, where the wastes are treated in an industrial waste-treatment plant, produces about 280 gallons of waste per barrel.

The largest quantity of wastes from breweries is usually unpolluted cooling water. Wash waters for equipment, kegs, bottles, etc., contain varying amounts of wort or beer, yeast, and acid or alkaline cleansing agents. Since absolute cleanliness of the equipment is essential the wash water comprises an important part of the waste flow. The residue from the mashing vats contains the spent grains. This grain is always recovered and sold either in a wet or dry state. The waste from dewatering this grain, if it is sold dry, is the strongest waste from a brewery. Mohlman found that this waste amounted to about 7.5 percent of the total waste flow. Spent hops occasionally discharged to the sewer and at least a part of the yeast which settles to the bottom of the fermentors is usually discharged with the other wastes. Spills or wastage of spoiled brews are other sources of wastes.

Character of Wastes

The Chicago studies indicated that brewery wastes have a sewered population equivalent, based on 5-day biochemical oxygen demand, of 19 per barrel of beer produced per day. Three 1-day tests at the Minster, Ohio, brewery showed a sewered population equivalent of from 6.4 to 15 per barrel per day, and an average of 11. The grain at this brewery is sold wet. A 2-day test at a Louisville brewery showed a population equivalent of 12 per barrel per day, exclusive of bottling wastes. At the Houston, Tex. plant, where the grain is sold wet and about 90 percent of the product is bottled, the population equivalent was found to be about 14 per barrel per day during experimental studies. Operating results at the waste-treatment plant indicate a population equivalent of about 12 per barrel per day.

The Chicago studies showed the average suspended solids content of the brewery waste to be 1.68 pounds per barrel, of which 31 percent was from the grain dewatering wastes. This corresponds to a sewered population equivalent of 8.4 per barrel per day, if the grain is dried, and 5.8 per barrel per day if the grain is sold wet. The Louisville brewery where the grain is dried showed a suspended solids population equivalent of 6 per barrel per day exclusive of bottling wastes. At the Houston and Minster breweries, where the grain is sold wet, the suspended solids population equivalents were 5.5 and 2.6 per barrel per day respectively.

Typical analytical results on brewery wastes are as follows:

Determination	Chicago studies		Louisville	Minster	Houston
	Grain squeezer waste	Total waste	Total waste	Total waste	Total waste
Biochemical oxygen demand, parts per million (5-day 20° C.)	25,700	1,200	419	1,028	858
Suspended solids, parts per million	8,550	650	244	305	411
Total nitrogen, parts per million	860	50		24	
pH	4.1	6.1	7.4	5.5	

Because of the more extensive sampling involved in the Chicago studies, these must be given more weight in determining average waste discharges than the other studies. The sewered population equivalent of typical brewery wastes on a biochemical oxygen demand basis averages about 19 per barrel per day if the grain is dewatered and 12 if sold wet. The corresponding suspended solids population equivalents can be taken as 9 and 6.

Pollution Effects

The polluting effects of brewery wastes are almost entirely due to the oxygen demand which they impose on the receiving stream. The wastes are often slightly acid but not to any important degree. The wastes contain numerous bacteria, none of which are harmful, and large numbers of yeast cells.

Remedial Measures

Brewers' grains are always recovered. They have a considerable market value as cattle food. In the Ohio Basin more than half of the breweries sell the wet grain. The larger ones and most of those in large cities are obliged to dry the grain because of the lack of an adequate local market for the grain. Selling the wet grain reduces the waste load appreciable. Spent hops also are sometimes sold to farmers for fertilizer although they have no great market value. The commonest methods of disposal are dumping on land and incineration. A part of the yeast from the fermentors often is reused in the process but from one-half to two-thirds of the yeast is wasted to the sewer. Recovery of this would effect an important reduction in the waste load.

The wastes are amenable to treatment by the common biological sewage treatment processes. Experimental studies at Houston showed that the primary sedimentation tanks preceding trickling filters reduced the biochemical oxygen demand and suspended solids by about 18 percent. Chemical treatment with various coagulants reduced the biochemical oxygen demand by from 50 to 75 percent but the results were erratic, large volumes of sludge were produced, and the sludge did not filter readily on a vacuum filter. The Hays process was also tested but biochemical oxygen demand reductions were found to be low and suspended solids reductions somewhat poorer than achieved by trickling filters. Trickling filters were found to give excellent results. Series operation of twin filters gave better results than parallel operation. With loadings of 15 pounds of 24 hour biochemical oxygen demand per 1,000 cubic feet of filter per day (equivalent to about 36 pounds of 5-day biochemical oxygen demand, based on parallel biochemical oxygen demand determinations) reductions of 90 percent in biochemical oxygen demand were found. On the basis of the experimental work a trickling filter plant was designed providing—

(*a*) Twin settling tanks providing detention periods of 1.5 hours each at maximum flows of 600,000 gallons per day.

(*b*) Twin dosing tanks.

(*c*) Twin circular trickling filters 100 feet in diameter and 6.5 feet deep equipped with rotary distributors. The filter media is 1¼ 2½-inch granite. Filters designed for maximum loadings of 12.8 pounds of 24 hour biochemical oxygen demand per 1,000 cubic feet of filter media per day.

(*d*) Final settling tank designed for 650 gallon overflow rate.

(*e*) Sludge digestion tanks, unheated.

(*f*) Sludge drying beds, pumps, etc.

This plant was constructed at a cost of about $70,000 and was placed in operation in November 1938. The filters and settling tanks have been operated in series. Sludge from the secondary and final settling tanks is concentrated in the primary settling tank before being pumped to the digester. The flow has averaged 280,000 gallons per day, the biochemical oxygen demand 882 parts per million, and suspended solids 458 parts per million. The plant has averaged about 92 percent removal of biochemical oxygen demand and 85 percent removal of suspended solids. The operating costs have been about 2 cents per barrel of beer. Operating charges on such a plant are relatively constant and do not vary greatly with variations in production.

An activated sludge-treatment plant was installed at the Minster, Ohio, brewery in 1936. The plant includes provision for preliminary chemical coagulation. Numerous operating difficulties have been encountered and, as yet, consistent results have not been obtained.

By far the commonest method of disposal of brewery wastes is to municipal sewers. Most breweries are located in the larger cities and are accessible to sewers. Only two of the breweries in the Ohio Basin are so situated as to require independent treatment. Since the treatment methods used are similar to those used for municipal sewage, there seems to be no reason why brewery wastes can not be treated satisfactorily at municipal treatment plants if they are designed for the additional waste load and if the plant is carefully operated. There is some indication that activated sludge plants are less satisfactory than trickling filters for secondary treatment of sewage containing large amounts of brewery wastes.

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(2) R. J. Bushee, Treatment of Brewery Wastes, Sewage Works Journal, 11, 295–307 (March 1939).

(3) S. L. Tolman, Operation of the Waste Treatment Plant of the Gulf Brewing Company, Houston, Texas, Ohio Conference on Sewage Treatment, 14th Annual Report.
(4) Correspondence with Gulf Brewing Company, Houston, Texas, F. P. Brogniez, Master Brewer, and L. L. Hahn, Jr., Chemist.
(5) Correspondence with Ohio State Health Department, F. H. Waring, Chief Engineer.
(6) Ohio River Pollution Survey, unpublished data.

Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–1

INDUSTRIAL WASTES

River Mileage Index No. *RB 89*

Type of Plant: *Brewery.* State: *Ohio.*
Name of Plant: *Openshaw Brewing Co.*
Municipality: *Palliston.* Main Watershed: *Rapid.*
County: *Marshall.* Subwatershed: *Beaver Creek.*
Address: *4th & Paragon Street.*
Source of Information: *F. A. Openshaw, Brewmaster.*
Plant Operation:
Ave. 40 hr. per week—40 plant employees.
Max. 48 hr. per week—50 plant employees.
Seasonal Variation: *Peak months—May 1—Sept. 30.*
6 Brews per week—210 bbl. per brew.

(Survey report continued on next page)

Survey by *George Spelvin.* Date: *8–29–39.*

Sewered Population Equivalent Computation:
Factors used *per 31 gal. bbl. of beer produced:*
B. O. D.: *12.* Suspended solids: *6.*
Sewered population equivalent* based on B. O. D.: *2,500.*
Sewered population equivalent* based on suspended solids: *1,300.*

Remarks: *Grain sold wet. Wastes to municipal treatment.*
Computation by: *G. P. G.* Date *7–3–40.* Cincinnati Office.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

*Rounded to nearest 100.

(*Typical inspection report continuation sheet*)

Openshaw Brewing Co., Palliston, Ohio.

Water Supply:
- Ave.—60,000 gallons per day.
- Max.—80,000 gallons per day.
- All water from municipal supply.

Raw Materials:
- 185,000 lbs. malt per year.
- 50,000 lbs. rice grits per year.
- 12,000 lbs. corn flakes per year.
- 30,000 lbs. hops per year.
  - Chemicals (per year) for cleaning:
    - 45,000 lbs. caustic soda.
    - 18,000 lbs. tri-sodium phosphate.

Products:
- 52,000 barrels of beer per year.
- 210 gallons per brew. Maximum of one brew per day.

Wastes:
- Spent grains sold to farmers (wet).
- Spent hops to city dump.
- Yeast wasted to sewer.
- Cooling water recirculated (refrigeration).
- Maximum waste flow about 70,000 gallons per day (350 gallons per bbl.)

Outlets: To city sewers and treatment plant. 1–15″ connection to 4th Street sewer. No manhole on plant sewer. Gaging opportunity poor.

Sanitary Sewage: With plant wastes to city sewers.

Remarks: Water consumption lower than average because of necessity of buying all water and of paying sewer rental based on water use.

BREWERY WASTES (Not an Actual Brewery)

Plant: Openshaw Brewing Co. State: Ohio Ref.No.: RB – 89

City: Palliston County: Marshall Main Watershed: Rapid River

Address: 4th and Paragon Sts. Sub-watershed: Beaver Cr.

Informant: F. A. Openshaw Title: Brewmaster Principal Product: Beer

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	40	280	40
Maximum	48	132	50

Seasonal variation: Peak Months May to Sept. inclusive

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	Municipal Supply	Total-All Purposes	Total-All Purposes	Filtered Chlorinated
Industrial	"	60,000 g.p.d.	80,000 g.p.d.	
Cooling	"			

RAW MATERIALS: - Malt: 1,850,000 lb. per year Rice: 500,000 lb. per year

Corn: 120,000 lb. per year Hops: 30,000 lb. per year

Yeast: Other: 45,000 Caustic Soda 18,000 lb. Tri – Sodium Phosphate per year for cleaning

PRODUCTS: - Beer 210 bbl. per brew Brews per week: Average 5 Maximum 6

52,000 bbl. per year Percent of Product Bottled:

WASTES: - Quantity: 70,000 g.p.d. (max.) How estimated: Water Consumption

Brewers grain: No Data available Disposal: Sold to Farmers (wet)

Spent Hops: " " " Disposal: City Dump

Yeast: " " " Disposal: Sewer

Treatment: To Municipal Treatment Plant

Analyses: Number: None Date: By whom:

Appearance: Could not inspect

OUTLET:- Where to: City Sewer (4th Street) through 15" Plant Connection

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities: Poor

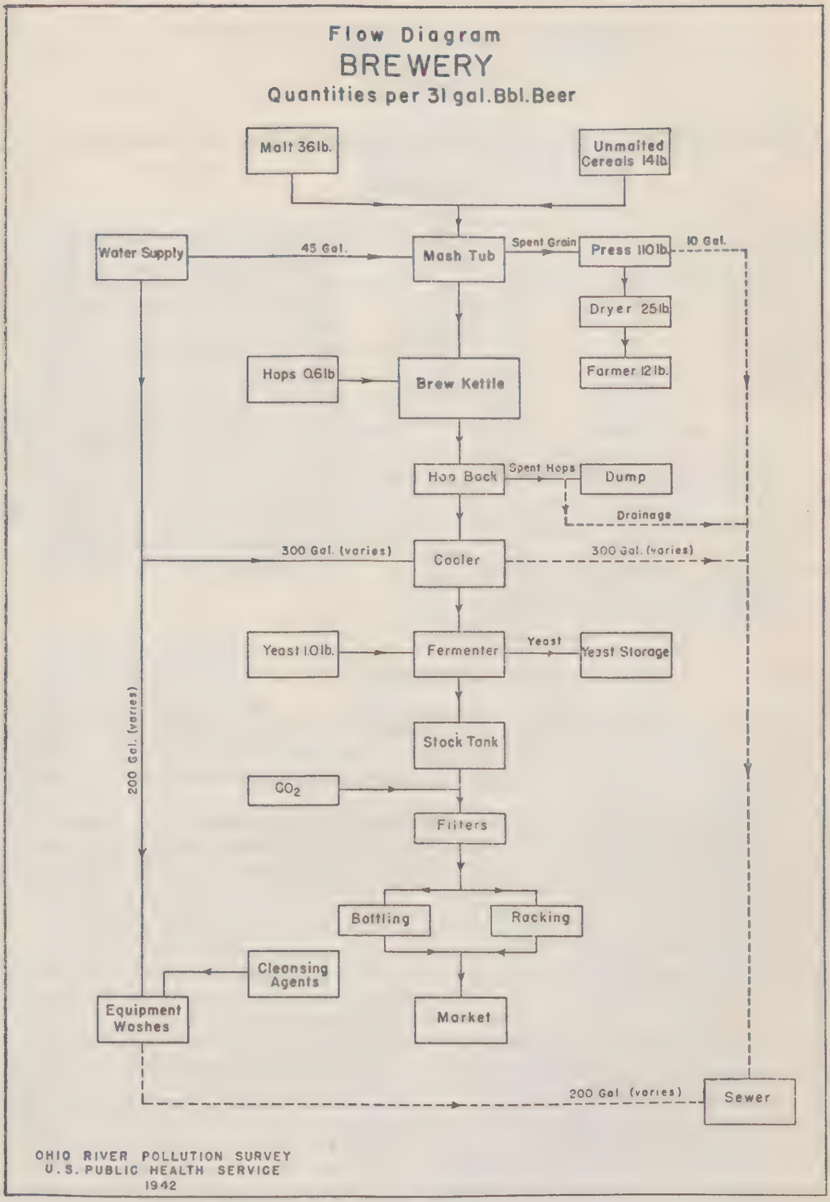
Conditions below outlet: Color: ——

Turbidity: —— Deposits: ——

SANITARY SEWAGE: Disposal: To City Sewer Persons tributary: 60

REMARKS: Water Consumption Lower than Average because of Necessity of Buying all Water and of Paying Sewer Rental Based on Water Consumption.

Survey by: George Spelvin Date: 8-29-39.


Flow Diagram
BREWERY
Quantities per 31 gal. Bbl. Beer
Malt 36 lb.
Unmalted Cereals 14 lb.
Water Supply
45 Gal.
Mash Tub
Spent Grain
Press 110 lb.
10 Gal.
Dryer 25 lb.
Farmer 12 lb.
Hops 0.6 lb.
Brew Kettle
Hop Back
Spent Hops
Dump
Drainage
300 Gal. (varies)
Cooler
300 Gal. (varies)
Yeast 1.0 lb.
Fermenter
Yeast
Yeast Storage
200 Gal. (varies)
Stock Tank
CO_2
Filters
Bottling
Racking
Cleansing Agents
Equipment Washes
Market
200 Gal (varies)
Sewer
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1942

APPENDIX II OF SUPPLEMENT D

CANNERY

An Industrial Waste Guide to the Canning Industry

CONTENTS

Abstract

The canning industry is highly seasonal, most canneries operating on only one or two products, with a working season of from 1 to 3 months per year. Some of the larger establishments operate throughout the year by canning such products as dried beans, hominy, and spaghetti during the periods when fresh vegetables or fruits are not in season.

Wastes from fruit and vegetable canneries consist primarily of wash water used to clean the raw material, floors, and equipment, water used in blanching, and spills of product at various points along the processing line. The wastes contain small bits of the product, pieces of skin, seeds, hulls, juice, etc., and have a color characteristic of the product being packed. The principal products canned in the Ohio Basin are tomatoes (and tomato products), corn, and peas.

The amount and strength of the wastes from canneries varies greatly but it is possible to estimate approximately the pollution load from a cannery of a given type in terms of its production. Representative figures representing the magnitude and strength of cannery wastes are shown on table Cn-1.

Variations of as much as 400 percent in the pollution load per unit of production have been found. The existence of this variation indicates a promising line of attack in correcting pollution at canneries whose wastes are greater in strength and magnitude than other canneries of the same product. Care in preventing the entrance of the stronger wastes, juice, garbage, etc., into the sewers can often accomplish substantial reduction in the waste load without treatment.

Fine screens (about 40 mesh) should be provided at every cannery, regardless of the method of waste disposal, to remove the coarser solids from the wastes. In general, these solids are light and do not settle well but float and form a scum. The fresh wastes are usually about neutral (varying of course with the pH of the water supply) but in a short time they become acid. Fresh wastes are much easier to treat.

Lagooning, often the only practical procedure at a small cannery, has proven an effective method of abating pollution at small rural canneries where the operating season is short, sufficient land available and odor nuisances unimportant. Sodium nitrate, suggested earlier in one of these guides, has been used to control odors.

TABLE CN-1.—*Representative waste flows and strengths from canneries producing various products*

Product	Waste flow, gallons per case [1]	Biochemical oxygen demand, 5-day, 20° C., parts per million	Suspended solids parts per million	Sewered population equivalent per 100 cases per day [1]	
				Biochemical oxygen demand [2]	Suspended solids [2]
Asparagus	70	100	30	35	9
Beans:					
Pork and	35	925	225	160	33
Green	35	200	60	35	9
Lima	250	190	420	240	440
Beets	37	2,600	1,530	480	235
Corn:					
Cream style	25	620	300	75	30
Whole kernel	25	2,000	1,250	250	130
Peas	25	1,700	400	210	40
Pumpkin, squash	[3 4] 25	6,400	1,850	800	190
Sauer kraut	3	6,300	630	100	8
Spinach	160	615	------------	490	------------
Succotash	125	525	250	330	130
Tomatoes:					
Whole	7.5	4,000	2,000	150	60
Products	70	1,000	500	350	150
Apricots	[4] 80	1,020	------------	410	------------
Grapefruit:					
Sections	56	1,850	270	520	63
Juice	5	[5] 310	170	8	3
Peaches, pears	[4] 65	1,340	------------	440	------------

[1] Case of 24 No. 2 cans except as noted.
[2] Based on per capita discharge of 0.167 pounds of 5-day biochemical oxygen demand and 0.2 pounds suspended solids per day.
[3] Per case of 24 No. 2½ cans.
[4] Size of can unknown.
[5] Exclusive of peel bin wastes.

Chemical precipitation is extensively used in cannery-waste treatment. Low annual charges, even at the expense of high operating costs, makes this process attractive in the seasonal canning industry. Lime alone, or with alum or various iron salts, are the principal chemicals used. The primary consideration in such treatment has been found to be raising the pH of the wastes to about 10. Reductions in biochemical oxygen demand of about 50 percent are common with this type of treatment. The undigested sludge dries in a week or less on open beds.

Trickling filters are not widely used in cannery waste treatment although numerous experiments have shown that they can accomplish biochemical oxygen demand reductions of the same order as they can in treating domestic sewage. The time required to reach peak efficiency is the principal difficulty with trickling filters in treating cannery wastes.

Some municipal treatment plants are successfully treating canning wastes in volumes considerably in excess of the ordinary domestic sewage. Chemical treatment, either at the cannery or at the treatment plant, has been found almost essential if the cannery wastes represent an appreciable portion of the total waste load. Both trickling filters and activated slude plants are being used successfully where complete treatment is required. Adequate design of the secondary devices on the basis of the biochemical oxygen demand loading is essential.

The cost of treating cannery wastes varies quite widely. In general, it is of the order of magnitude of 1 cent per case or less. In some cases, however, it may amount to as much as 2 cents or more per case. Lagooning, where it is at all practicable, is usually the cheapest method. Chemical treatment costs considerably more, and trickling filters still more.

Description of Process

Fruit and vegetable canneries are important sources of industrial wastes. The nature of the industry requires that large amounts of water be used to insure cleanliness of the product. On the whole, the industry is growing. There are about 3,000 such establishments in the United States and about 250 were visited during the Ohio River pollution survey. Although a wide variety of foods are canned, the most important ones in the Ohio River Basin are tomatoes, corn, and peas. The pollution problems attending the canning of these products are discussed in this guide and some additional information on the canning of other products is included.

CORN

Corn is planted in the early summer and harvested between the middle of August and the latter part of September.[1] The grower delivers the ears in husks to the cannery where it is weighed, unloaded, and sent to the storage bin. From the storage bin the corn goes to—

(*a*) Huskers, which remove the husks, butts, and silks. These are conveyed to a stack or silo. The corn passes on to the—

(*b*) Sorters and trimmers, who remove foreign material, defective ears and parts. The refuse goes to the stack or silo and the corn passes on through the—

(*c*) Washer where, by a process of rolling and scrubbing under powerful water sprays, loose husks, dirt, etc., are removed.

(*d*) Cutters cut and scrape the kernels from the cob, which is sent to the stack or silo. The kernels move on to the—

(*e*) Silker, a device consisting of screens and shakers, which remove any remaining silks. These are discharged to the stack or silo. The corn is sent to the—

(*f*) Batch mixer (fill-and-draw type), in which brine is added to the corn in a ratio of about 1 to 4. The contents of the mixer are agitated and preheated to a temperature of 180° to 190° F. before being pumped to a—

(*g*) Blending mixer (continuous-flow type), the purpose of which is to maintain uniformity of product. The mixture is pumped to the—

(*h*) Filler which fills the cans. These then go to a—

(*i*) Closing machine, which seals covers on the cans. The cans are cooked in a—

(*j*) Retort, where steam is used to maintain a temperature of about 250° F. for about 70 minutes. After cooking, the cans are—

(*k*) Cooled, sometimes in the retorts by removing the covers and applying water, but more commonly in a long cooling tank through which the cans pass on a conveyor.

After cooling, the cans are cased and stored in the warehouse. Before being shipped the cans are passed through a shaking machine to break up the contents and through a labeling machine.

The average time from the truck to the warehouse is about 2 hours, of which 70 minutes is spent in the retorts and about 20 to 25 minutes in the cooling tank.

The above process applies to the canning of cream-style corn which constitutes the bulk of the corn pack. In packing whole-kernel corn, bleeding of the cream from the kernel is minimized by a special cutting process and the juices adhering to the kernels are washed away.

PEAS

Peas are usually planted during April and require a 50–75 day growing season. The harvest seasons in Ohio and Wisconsin vary from June 1 to July 10 and June 15 to August 10, respectively.

The vines are cut with a mowing machine, raked or bunched, and loaded on truck or wagon by which they are transported as quickly as possible to vine stations to prevent wilting. Vining may be done at the cannery or at several centralized locations in the growing area. The latter practice has some definite advantages. Long hauls to the cannery and back to the farms for animal feeding are eliminated; vine stacks are smaller and are located where the soil usually is able better to absorb stack juices before they reach a natural watercourse. The viner removes the vines and pods and delivers the shelled peas to boxes. These are now ready for the cannery processing line.

The operations in a pea-canning factory are usually as follows:

(*a*) Weighing scales.

[1] These dates apply to conditions in the northern half of the Ohio River Basin. In other climates growing seasons and time of harvest are different.

(*b*) Clipper, screen or cleaner. Pieces of pods, stems, and leaves are removed by screens and blown away.

(*c*) Washer. Squirrel-cage type, inside of which is perforated pipe delivering heavy water spray. In some plants a riffler precedes the squirrel cage as part of the washing process.

(*d*) Grader. Where grading for size is accomplished by passing through rotating cylinder screens or by a flotation process in brine solutions.

(*e*) Blancher. A perforated cylinder containing a spiral. The cylinder is rotated at a speed which will pass the peas through in a given time. Water and steam are admitted at the downstream end and discharged at the inlet end of the cylinder. The time of blanching depends on the size and condition of the peas, varying between 5 and 15 minutes. The blanching temperature maintained in any particular cannery appears to be kept fairly constant. Some canners blanch at 180° F. to 190° F. and others at 208° F. to 212° F. The percentage of splits is said to be higher at the higher temperatures. The peas are discharged from the blancher to a—

(*f*) Washer, for separation of split peas and water.

(*g*) Picking table, where any remaining foreign material, split or bruised peas are removed manually.

(*h*) Filler; brine is added and the can filled.

(*i*) Closing machine seals the cover on the can.

(*j*) Retorts; cooking at about 240° F. for 30 to 35 minutes. Some packers use a slightly lower temperature and shorter cooking period. Upon completion of the cooking process the cans are placed on endless conveyors carrying them through the—

(*k*) Cooling tank, which is expected to bring the temperature of a No. 2 can below 100° F. in about 7 minutes. About 25 minutes are required to reduce the temperature of a No. 10 can below 100° F.

After cooling, the cans are cased and stored in the warehouse. Labeling is usually done at the time of shipment. Under normal operating conditions the complete process takes less than 1 hour.

TOMATOES

Tomatoes are planted or transplanted in the early summer and harvested between the middle of August and the latter part of September. As the tomatoes ripen, they are picked, placed in five-eighths bushel (29 to 34 pounds, net) hampers, and delivered to the cannery.

The process of canning whole tomatoes usually consists of the following steps:

(*a*) Soak tank, containing clear water which softens and loosens dirt and foreign matter. After a brief detention period (3 to 5 minutes) air, applied through perforated pipes in the bottom of the tank, raises the tomatoes to the elevation belt at the downstream end of the vat. The conveyor carries them under—

(*b*) Water sprays, which remove dirt and foreign material loosened in the soak tank.

(*c*) Picking and sorting table; off color, damaged, and defective fruit are removed manually.

(*d*) Water spray; the second spray removes any remaining dirt or foreign matter.

(*e*) Scalder (hooded conveyor), in which live steam is applied to the tomatoes for periods of 15 seconds to 2 minutes (depending on the head of steam available and condition of the tomatoes), to loosen the skin on the fruit.

(*f*) Cold water spray, to loosen further the skin and check the heat in the fruit.

(*g*) Peeling and coring table; skins and cores are removed.

(*h*) Fillers (usually hand operation on whole tomatoes). Salt is added at the rate of about 25 grains per No. 2 can (20-ounce). Tomatoes are placed in the can and voids filled with juice.

(*i*) Exhauster, a covered conveyor containing steam jets. The temperature is maintained between 150° F. and 180° F. for a period of 3 to 5 minutes.

(*j*) Closing machine seals the cover on the can. Cooking may be accomplished in retorts but more general practice is by the use of a—

(*k*) Continuous cooker, a long, narrow tank containing water at a temperature of 212° F. The cans in small wire crates pass through the tank on a conveyor. The time of cooking is generally 20 to 30 minutes, depending on the ripeness of the tomato. The crates of cans are arranged in open stacks for—

(*l*) Air cooling.

In the processing of most tomato products peeling is omitted. The process in making tomato pulp is the same as that of whole tomatoes through the scalder, (*a*) to (*e*), inclusive. The scalded tomatoes pass to a—

(*f*) Pulper; which removes skins, seeds, and cores.

(*g*) Cooker (fill and draw type), consisting of a large wooden or copper tank (may be under slight vacuum) heated by steam passing through copper coils at a pressure of 100 pounds or more per square inch. Cooking and evaporation is continued until a specific gravity of from 1.035 to 1.050 is reached.

(*h*) Finishing machine, consisting of fine screens which remove any foreign material.

(*i*) Holding tank, equipped with heating coils at temperature 180° F. to 190° F. and agitating units.

(*j*) Filler. Salt is added as cans are filled.

(*k*) Closing machine, which seals the cover.

(*l*) Cooker or sterilizer. This step may be omitted.

(*m*) Air cooling.

The manufacture of catchup is very similar to that of pulp except that salt vinegar, sugar, and spices are added to the cooker. Tomatoes are not peeled nor cored for catchup production. Catchup is usually packed in glass and often sterilized or cooked briefly after closing.

Chili sauce differs from catchup in that the tomatoes are peeled and cored as for canning whole tomatoes. They are then run through a chopping machine. More onions, garlic, and peppers are generally employed in the spicing and spices may be placed in a sack which is later removed. The cooking and handling are similar to that used for catchup, but the finishing operation (fine screening) is eliminated. Packing in glass is customary.

Raw Materials and Products

CORN

The raw materials used in corn canning are corn and brine. The brine is made up according to the desires of the plant superintendent. It usually contains from 10 to 20 pounds of salt and from 50 to 100 pounds of sugar per 100 gallons of water.

Under average conditions a ton of corn as received at the cannery produces about 665 No. 2 cans (net weight 20 ounces per can). Since about 20 percent of the volume is brine the net weight of the canned corn from 1 ton of material as received is about 665 pounds and the loss between raw material and product about 67 percent. The flow diagram shows the approximate amounts of various substances lost during the process and the method of disposal of each.

PEAS

The raw materials used are graded peas and brine. Brine is made up according to grade of product packed. Ten pounds of salt and 20 to 25 pounds of sugar per 100 gallons of water appears to be a fair average of ingredients used. This solution is added to the peas at the filler in the ratio of about 1 to 2. A 20-ounce (net weight) No. 2 can usually contains 12 to 14 ounces of peas and 6 to 8 ounces of brine.

In packing standard grades a yield of 2,400 No. 2 cans per ton of shelled peas may be expected. If each can contains 13 ounces of peas, the loss between raw material and product would be 2 percent. In packing fancy grades about 2,000 cans of No. 2's may be expected from a ton of shelled peas. On the basis of 13 ounces per can, the loss between raw material and product would be 18 percent Losses are said to vary between 2 and 15 percent during processing.

TOMATOES

In processing whole tomatoes the number of No. 2 cans per ton will vary from slightly under 700 to over 1,100. On an average 900 to 1,000 cans per ton is expected. Salt is added at about 25 grains per No. 2 can. Other ingredients, such as sugar and spices, added to tomato products are not in quantities sufficient to affect the weight of the final product.

Using 950 cans per ton as an average, the weight of product derived from 1 ton of tomatoes as delivered at the plant would be 1,187 pounds or a loss of about 40 percent. The principal losses are represented by defective, bruised, or badly damaged fruit (culls), skins, cores, and seeds.

Losses on tomato products appear, in general, to be somewhat higher than those on whole tomatoes. In studies at an Ohio cannery, Kimberly found the losses on pulp and juice to be slightly over 50 percent. It is probable that this loss will

vary from around 40 percent to over 50 percent on all tomato products, depending on the condition of the raw material. Considerable amounts of tomato products are bottled in glassware. It is possible that breakage of filled glass containers may increase the percentage of loss.

EMPLOYEES

About 90 employees are required to operate a 1-line corn cannery receiving 75 tons of corn and packing 2,000 cases of 24 No. 2 cans per day. The ratio of employees to product is usually between 3 and 6 employees per 100 cases per day. This ratio is low in the larger plants and high in the smaller ones.

Twenty-five or thirty employees can operate a one-line pea cannery, packing fancy grades, which of course require more sorters than are needed on standard grades. One cannery official in Ohio estimated that a plant packing standard grades could operate one line with a minimum of 10 to 15 employees. The average daily pack in a one-line plant would be about 2,000 cases of No. 2's. The ratio of employees to product would then be 5 to 15 persons per 1,000 cases of product. More persons are employed per unit of product in a one-line plant than in a plant operating several lines.

A one-line tomato cannery receiving 40 to 50 tons of tomatoes per day and packing 1,500 to 2,000 cases of No. 2 cans of whole tomatoes will usually employ between 90 and 120 persons. Peeling and coring require 70 to 90 persons; about 4 are required for sorting and the remaining employees have various other duties. The ratio of employees to product is 5 to 8 persons per 100 cases of No. 2 cans packed per day. On products where the tomatoes are not peeled, the ratio is much smaller.

Sources and Quantity of Wastes

All three types of canneries have two types of waste in common; the continuous flow of wash water used in the canning operation and the wastes from the general clean-up of floors, tables, and equipment at the end of the day's run or more frequently. Wastes more or less peculiar to the various products are as follows:

Peas: Blancher wastes. This is a continuous discharge and, in addition, the blancher is dumped periodically.

Tomatoes: Soak tanks. These are dumped periodically.

Corn and peas: Silage liquor. Drainage from stacks and silos produced by the decomposition of husks, cobs, vines, pods, etc.

If the cans are water cooled, the cooling water adds to the volume of wastes, but it is unpolluted. In some canneries cooling water is reused.

The amounts of water used in various canneries of the same general type varies greatly depending on such factors as the method of cooling, type of equipment, housekeeping methods, adequacy and cost of water, and method and cost of waste disposal. The bulk of the wastes (exclusive of cooling water which presents no pollution problem) comes from the washing operations and from the general clean-up of floors and equipment.

CORN

Corn canneries inspected in connection with the Ohio River Pollution Survey indicated an average waste flow of about 25 gallons per case which amounted to about 60 to 65 percent of the total water used. Studies of a cannery at Canal Winchester canning cream-style corn showed an average waste flow of 23.8 gallons per case exclusive of 16.7 gallons per case of condenser and cooling water. The waste flow during the 11-day test varied from 14.0 to 43.3 gallons per case and the condenser flow varied from 10.2 to 23.8 gallons per case. A 2-day test indicated that wastes from the clean-up at the end of the day amounted to about 1.5 gallons per case.

Four Wisconsin canneries reported an average waste flow of 24 gallons per case over a 4-year period. The Cedarburg, Wis., cannery reported a waste flow of 20 gallons per case during the 1938 canning season. These flows are exclusive of cooling water.

No data are available on the exact amount of silage liquor produced, but the quantity is known to be small.

PEAS

Pea canning produces approximately the same amount of waste per case as corn canning. The Wisconsin State Board of Health states that a two-line pea cannery packing 100,000 No. 2 cans per day will use about 100,000 gallons of water. Eldridge gives a volume of 25 gallons per case.

Studies in Wisconsin during the past 7 years indicate an average waste flow of slightly more than 1 gallon per No. 2 can. The average for the 7-year period, covering 55 separate reports and representing about 1,000 packing days, was 1.19 gallons per No. 2 can, the minimum being 0.58 and the maximum 2.33 gallons. These studies indicated that "pea canneries are being satisfactorily operated with a water usage of two-thirds of a gallon per No. 2 can, exclusive of cooling and boiler water."

One Ohio canner who operates a five-line plant states that his water consumption is about 20 gallons per case of No. 2's, including cooling water. Another Ohio canner operating a one-line pea cannery uses 25 gallons per case of No. 2's exclusive of cooling water. It appears that a one-line plant will have a somewhat higher per case consumption than a plant with more lines.

The Snider Packing Co., Albion, N. Y., used 336,000 gallons of water in packing 15,000 cases of No. 2 cans of peas. This represents about 22.4 gallons per case.

Blancher wastes constitute about 10 percent of the total volume of wastes. Kimberley reports that a pea cannery producing a total volume of 200,000 gallons of waste per day produced an average of 17,500 gallons of blancher liquor.

The amount of stack or silo liquor can vary considerably, depending upon the water content of the stack. Wisconsin reports that about 1,650 gallons of liquor will drain each day during dry weather from a vine stack produced when 1,000 cases of peas are packed each day. A stack from 100 acres leaches from 30 to 40 thousand gallons of waste over a period of from 30 to 40 days.

Twenty-five gallons per case seems to be a fairly representative waste volume from a pea cannery. This is exclusive of cooling water and stack liquor.

TOMATOES

Tomato canneries packing whole tomatoes generally use much smaller amounts of water than pea or corn canneries. Data from a survey of such canneries in connection with the Ohio River Pollution Survey showed waste flows ranging from 1.5 to 40 gallons per case where reasonably accurate data on water consumption were available. Other studies have shown the following waste flows:

Three gallons per case.—A Maryland cannery packing whole tomatoes and making pulp of the peels estimates its waste flow to be about 3 gallons per case of No. 2 cans.

Five gallons per case.—A Michigan cannery receiving 100 tons per day and packing whole tomatoes and puree was estimated to have waste flows of 210 to 230 gallons per ton or slightly over 5 gallons per case.

Seven and five-tenths gallons per case.—Hommon, in studies at Amelia, Ohio, in 1916, found 0.50 gallon of wastes produced per No. 3 can of whole tomatoes (net weight No. 3 can, 2 pounds). This is equivalent to about 7.5 gallons per case of No. 2 cans.

Information from a Michigan cannery indicates an average waste flow of 295 gallons per ton or about 7.5 gallons per case of No. 2 cans. This cannery packs whole tomatoes and puree and recovers seeds. Some indication is shown of a decrease in volume of wastes per ton as the pack increased.

These figures indicate that about 7.5 gallons of waste per bushel of tomatoes or per case of No. 2 cans is typical of a cannery packing whole tomatoes.

TOMATO PRODUCTS

Tomato-products canning requires considerably larger amounts of water than whole tomato canning. Data from the Ohio River Pollution Survey on five plants canning only tomato products and buying water from municipal supplies indicate waste flows of from 30 to 90 gallons per case of No. 2 cans. Other studies show the following:

Thirty-eight to ninety-five gallons per bushel.—The report on the Albion, N. Y., studies shows waste flows on the canning of tomato products varying between 69.5 and 94.0 with an average of 83.4 gallons per bushel corresponding to packs of 2,630 to 6,687 bushels of tomatoes. However, these same studies indicated that on a pack of 11,650 bushels the water consumption was about 587,000 gallons which corresponds to a bushel rate of only 38.6 gallons of water as waste.

Fifty to one hundred gallons per bushel.—One author states that volumes of waste from tomato-products canning may vary from 50 to 100 gallons per bushel of tomatoes received.

Eighty gallons per bushel.—Flow measurements during 1935 and 1936 at a tomato-soup plant near Chicago showed average flows over 11-day periods of

78 and 92 gallons per bushel (40 bushels per ton), respectively, or an average of 80 gallons per bushel.

These figures indicate that 60 gallons of waste per bushel of tomatoes is typical of a tomato-products plant. The variation indicated is from 30 to 100 gallons per bushel.

Character of Wastes

Wastes from the canning of cream style corn have a biochemical oxygen demand of about 620 parts per million and about 300 parts per million of suspended solids. The clean-up wastes are stronger than the continuous wastes during operations. Variations in strength from 50 to 200 percent of the above values are common. In canning cream style corn the starchy liquor washed from the cut kernels increases the pollution load considerably. The biochemical oxygen demand of the combined wastes from whole-kernel corn canning is about 2,000 parts per million and the suspended solids about 1,250 parts per million. Neither of these values includes the silage waste which is much stronger, having a biochemical oxygen demand of the order of 30,000 parts per million.

Pea canning wastes have an average biochemical oxygen demand of about 1,700 parts per million and about 400 parts per million of suspended solids. Variations in biochemical oxygen demand of from 500 to over 7,000 have been noted in different plants. The strongest wastes are those from the blancher. The continuous blancher wastes contain a large amount of starch and have a biochemical oxygen demand of from 10,000 to 15,000 parts per million. They are relatively low in suspended solids. The blancher is dumped once or twice a day and these wastes may be from two to three times as strong as the continuous discharge. The average figures for the combined cannery wastes do not include silage liquor which has a biochemical oxygen demand of from 50,000 to 75,000 parts per million, from 1,500 to 2,000 parts per million of suspended solids, and a pH of from 3 to 4.

Wastes from whole tomato canning are relatively high in biochemical oxygen demand although the volume is small. Analyses at a number of plants show an average of about 4,000 parts per million of biochemical oxygen demand with variations from 2,000 to 7,000 parts per million. Wastes from the general clean-up at the end of the day's operations constitute from 20 to 30 percent of the total waste and are somewhat stronger than the wastes produced during operation. The wastes contain an average of about 2,000 parts per million of suspended solids but variations of from 600 parts per million to 4,000 parts per million have been found. The pH of the wastes is usually between 4 and 6, although when quite fresh the pH may be higher.

Tomato products canning wastes are more dilute than the wastes from whole tomato canning. The biochemical oxygen demand averages about 1,000 parts per million but may vary from about 200 to 2,000 parts per million. Suspended solids are usually about 500 parts per million with comparable variations.

SEWERED POPULATION EQUIVALENTS

On the basis of the average flows and analyses from various canneries, the sewered population equivalents shown on table Cn-2 have been determined.

TABLE CN-2.—*Sewered population equivalent of cannery wastes based on biochemical oxygen demand and suspended solids*

Product	Sewered population equivalent per 100 cases of No. 2 cans per day	
	Biochemical oxygen demand [1]	Suspended solids [1]
Corn (cream style)	75	30
Corn (whole kernel)	250	130
Peas	210	40
Whole tomatoes	150	60
Tomato products	350	150

[1] Based on 0.167 pound of 5-day, 20° C. biochemical oxygen demand and 0.20 pound of suspended solids per day.

Pollution Effects

The polluting effects of cannery wastes are due to their oxygen depleting characteristics. They contain no harmful bacteria nor toxic substances. In general, they are colored and this effect may make the receiving water unsightly. The solid material is light and does not settle readily but has a tendency to float and form a scum.

Remedial Measures

WITHIN THE CANNERY

A number of steps can be taken within a cannery which will reduce the polluting effects of its wastes at relatively small cost. These steps, which are often quite attractive in reducing cost of subsequent treatment, include—

(a) Removal of all gross solids such as husks, cobs, peelings, culls, trimmings, etc., before they can enter the sewers. These should be disposed of separately, either by returning them to farms as fertilizer or animal food or in some other manner which will prevent their entrance into natural watercourses.

(b) Proper adjustment of filling machines to reduce spills during this operation. Unavoidable spills of small amounts of material can be disposed of with garbage.

(c) Separate disposal of any stack or silage liquor in some manner which will prevent its entrance into natural watercourses.

(d) Fine screening of all polluted liquid wastes on a 40- to 60-mesh rotating or vibrating screen equipped to prevent clogging of the screen.

Effective treatment following screening has been provided by lagooning, chemical precipitation, trickling filters, intermittent sand filters, and by treatment in municipal plants with domestic sewage. Plain sedimentation without the aid of chemicals removes little of the biochemical oxygen demand of most cannery wastes although some experiments have shown it to be effective with tomato wastes.

LAGOONING

Lagooning may be satisfactory at rural canneries where ample space is available, the operating season short, and the creation of an odor nuisance of no great importance. Relatively little purification takes place in the lagoon, but if it is large enough to hold an entire season's flow or a major part thereof, the wastes can be discharged in small amounts over long periods of time when temperatures are low and stream flows high and thus avoid polluting the receiving stream to any great extent.

The lagoon should be shallow, and the dikes or walls well built and impervious in order to prevent wash-outs or other accidental discharges. Diversion ditches may be necessary to prevent the entrance of surface water. Seepage into the soil and evaporation may dispose of a part of the waste but, in the Ohio Basin and, in general, throughout the eastern half of the United States, evaporation is not very effective. The lagoon should be emptied and cleaned before each operating season. If this is not done, the deposited solids will soon clog the soil openings and prevent seepage. The effluent from the lagoon is often disposed of by broad irrigation where suitable tracts of land for this purpose are available.

The principal disadvantages of lagoons are the odor nuisances they create and the serious consequences of accidental discharges due to structural failure or bad operation. Careful operation is as necessary with a lagoon as with any treatment plant, but unfortunately they seldom receive such operation. A preliminary edition of one of these guides suggested that odor nuisances can be reduced or entirely eliminated by adding sodium nitrate to the lagoon. Such treatment has been used on several occasions to eliminate odors due to various types of wastes and experimental studies by the National Canners Association of its application to lagooned cannery wastes indicated that the addition of enough nitrates to satisfy 50 percent or possibly less of the 5-day biochemical oxygen demand of the wastes not only prevented odors but reduced the biochemical oxygen demand by from 66 to 76 percent. Results of a trial at an Illinois cannery should be available soon.

CHEMICAL TREATMENT

Chemical precipitation has been extensively studied and widely used as a method of treating cannery wastes of various kinds. This method of treatment is particularly well adapted to canneries with short operating seasons because of its low first cost. The primary consideration has been found to consist in raising the pH of the waste to at least 10. Lime is used to do this since it is the cheapest chemical for the purpose. The effectiveness of the treatment is greatly increased by the addition of other precipitants such as various iron salts, alum, and zinc chloride. In general, the fill and draw plan of operation has been found preferable to the continuous-flow plan for moderate-sized installations.

Corn-canning wastes are considered harder to treat with chemical precipitation than tomato- or pea-canning wastes. Table Cn–3 shows the results of experimental treatment at Canal Winchester using alum and soda ash at rates of 20 and 8 grams per gallon, respectively, during the first run and 15 and 5 grams per gallon during the second run.

TABLE Cn–3.—*Chemical precipitation results, straight factory run wastes*

[Results in parts per million]

Determination	First run			Second run		
	Influent	Effluent	Percent removed	Influent	Effluent	Percent removed
5-day biochemical oxygen demand	797	525	34.2	582	450	22.7
Oxygen consumed	930	486	47.8	318	289	11.9
Organic nitrogen	15	6.7	55.2	11.8	6.7	43.2
Solids:						
Total suspended	273	100	63.3	311	212	31.9
Volume suspended	256	84	67.2	182	80	56.2

These results show relatively low biochemical oxygen demand removals.

Experiments with full-sized treatment units at the Cedarburg, Wis., cannery during the corn pack showed that much better results can be obtained. The coagulants used with lime included ferrous sulfate, ferric sulfate, ferric chloride, zinc chloride, alum, and bentonite. Of these, ferrous sulfate, and zinc chloride gave the best biochemical oxygen demand removals. Table Cn–4 shows the results of these experiments.

TABLE CN-4.—*Results obtained by the chemical treatment of corn waste, in quantities (batches) of 11,350 gallons*

Lime added per 1,000 gallons	Chemical added per 1,000 gallons	pH raw	pH treated	5-day biochemical oxygen demand: Raw	5-day biochemical oxygen demand: Treated	5-day biochemical oxygen demand: Reduction	Oxygen consumed: Raw	Oxygen consumed: Treated	Oxygen consumed: Reduction	Raw: Total solids	Raw: Total volatile solids	Raw: Suspended solids	Raw: Volatile suspended solids	Treated: Total solids	Treated: Total volatile solids	Supernatant
	Pounds															
Pounds	Zinc chloride			Parts per million	Parts per million	Percent	Parts per million	Parts per million	Percent	Parts per million	Parts per million	Parts per million	Parts per million	Parts per million	Parts per million	
6	0.75			985	136	86	800	175	78	2,394	1,406	316	274	2,212	186	Clear.
7	2.25	7.6	11.9	740	114	85	1,460	646	56	2,340	1,488	188	164	2,078	602	Milky.
6	2.55	7.9	11.8	920	246	74	1,610	720	55	2,648	1,730	218	206	2,042	640	Clear.
6	3.0			1,260	360	79	2,000	825	59	3,120	2,266	512	498	2,360	868	Do.
6	2.0	5.9	11.0	1,345	195	85	825	415	50							Slightly cloudy.
6	2.0	6.0	10.9	1,190	385	68	1,930	850	56							Cloudy.
6	2.0	6.5	10.9	1,350	465	66	2,090	1,475	29							
6	2.0			1,050	513	51	875	300	66	2,326	1,430	180	140	1,872	792	Cleu
6	2.5			1,120	355	68	1,000	500	50	2,498	1,740	214	210	2,288	956	Clo
6	3.25	6.9	12.4	1,460	410	72										Do.
6	3.25			1,835	510	[1] 72										Cloudy.
7	6.8			2,060	515	[1] 75										Clear.
6	4.6			1,750	430	[1] 75										Do.
	Ferrous sulfate															
10	8.4			1,760	480	73	1,150	620	47	3,086	2,278	432	432	2,752	936	Do.
10	10.0	7.8	12.1	1,490	300	80	2,109	800	62	3,248	2,448	546	546	2,582	580	Do.
10	8.4	8.0	12.5	1,530	310	80	1,950	666	66	3,968	2,256	809	800	2,698	680	Do.
10	8.0		12.5	1,860	368	81	2,150	833	61	3,298	2,434			2,752	780	Slightly cloudy.
8.8	3.8	7.4	12.0	1,270	236	81	606	465	23	2,320	1,478	502	500	2,652	740	Clear.
6.6	3.8	7.3	12.3	1,100	245	79	950	670	30	2,700	1,828	438	436	1,960	640	Do.
8	8.0		13.4	2,250	370	82	2,100	433	79	3,696	2,756	878	868	2,389	689	Do.
6	4.8	7.8	11.5	2,150	555	74	2,050	833	59	3,098	2,752	1,161	1,144	2,486	946	Cloudy.
8	8.0	7.5	13.3	2,160	513	76	2,600	900	65	4,150	3,114	936	926	2,834	976	Slightly cloudy.
6	6.5			2,400	570	80	2,300	933	59	3,782	2,856	1,161	1,161	2,676	1,142	Do.
8.8	8.0			1,770	355	80										Do.
8.8	8.0			2,040	460	77										Do.
8.8	8.8			2,020	510	75				4,852	3,804	1,146	1,134	3,348	1,178	Clear.
6	4.8			2,115	422	[1] 80										Cloudy.
8	8			3,480	595	[1] 83										Slightly cloudy.
8.8	8			2,020	358	[1] 82										Do.
8.8	8.8			2,850	1,005	[1] 65										Clear.
8.8	6.1			1,390	425	[1] 69										Do.
10	9.5			2,250	760	[1] 69										Cloudy.

[1] Results obtained by supplemented dilution water.

Methods of Treating Cannery Wastes, by Warrick et al., states, "Experience on both small and large scale operation has shown that if the ferrous sulfate is added in a single dose, the floc produced is small and slow in settling and the supernatant liquid remains milky. Further additions of ferrous sulfate are then necessary to produce the desired water-clear supernatant liquid. For example, the addition of 5 pounds of ferrous sulfate followed by four successive 1-pound additions, making a total of 9 pounds, produced a clear supernatant liquid. When, however, 9 pounds of ferrous sulfate was added in a single dose, the supernatant remained cloudy and further addition was required for clarification.

"In regard to this phenomenon, the following theory is advanced: When an amount of iron previously shown to be sufficient to produce in stage precipitation a water-white supernatant liquid is added to the limed waste in a single dose, it fails to clarify because the surface of the floc becomes coated with colloidal starch. The ability of the floc to absorb additional colloidal starch is thus destroyed. When, however, the same amount of iron is slowly added, fresh surfaces are built up on the flocs, which are then able to adsorb additional amounts of colloidal starch. The adsorption capacity of the surface of a floc is limited and must be renewed by the addition of more of the floc-forming material.

"Numerous large-tank treatments conclusively showed that when the lime is added slowly over a period of 5 to 10 minutes while the mixing agitator is revolving, the resultant floc, when mixed with the second precipitant, gives a more rapid settling final floc, leaving a clear supernatant. Physical observations indicated that if the lime is added at a rapid rate or while the tank is filling, the supernatant is cloudy and the floc slow in settling. After the slow addition of lime, followed by stage addition of the second precipitant, the mixing agitator should not be allowed to revolve longer than 1 minute after the last chemical addition." These results may explain some of the unsatisfactory results experienced elsewhere in chemical treatment of corn wastes.

The following conclusions were reached in the above-mentioned bulletin: "An oxygen demand reduction of approximately 70 percent was obtained on screened corn waste by the addition of approximately 9 pounds of lime and 8 pounds of ferrous sulfate or 6 pounds of lime and 2 to 6 pounds of zinc chloride per 1,000 gallons of waste when the described procedure is used. A dosage of 8 pounds of lime and 3 pounds of ferric chloride per 1,000 gallons of screened waste reduced the oxygen demand approximately 57 percent. A dosage of 8 pounds of lime and 7 pounds of ferric sulfate per 1,000 gallons of screened waste reduced the oxygen demand 46 percent."

Pea-cannery wastes are treated by chemical precipitation at many plants. Studies by the Wisconsin State Board of Health in 1926 indicated that reductions in biochemical oxygen demand of 50 to 75 percent could be obtained by the application of 7¼ pounds of lime and 3¼ pounds of ferrous sulfate per 1,000 gallons of waste. Later experiments showed lower efficiencies as shown in table Cn-5. These experiments indicated that the best coagulant with lime was zinc chloride. Later results on plant scale operations showed much lower reductions (24 percent). Ineffective mixing and improper control of chemical feed were stated to be the causes of the difference.

TABLE Cn-5.—*Results obtained by the treatment of pea waste with various chemicals, in quantities of 100 gallons*

Lime added per 1,000 gallons	Chemical added per 1,000 gallons	pH	5-day biochemical oxygen demand: Raw	Treated	Actual reduction	Average reduction	Floc	Supernatant
	Pounds							
	Ferrous sulfate							
Pounds			*Parts per million*	*Parts per million*	*Percent*	*Percent*		
7.0	2.9	10.6	1,500	460	69		Good	Clear.
7.0	3.0		2,370	1,330	44		do	Slightly cloudy.
7.0 [1]	3.0		3,130	1,780	43		do	Clear.
7.0 [2]	3.0		590	400	32	47	do	Do.
	Alum							
7.0	2.9	10.6	1,500	400	41		do	Do.
7.0	3.0	9.7	1,880	880	54		do	Fairly clear.
7.0	3.0		3,230	2,070	36		do	Clear.
7.0	5.5	9.6	1,030	830	19	45	do	Do.
	Ferric chloride							
7.0	3.0		2,470	1,510	39		do	Do.
5.5	1.25	9.8	1,270	720	43		do	Do.
8.25	3.75	9.8	1,270	830	35	39	do	Do.
	Ferric sulfate							
7.0	3.0		2,130	1,780	16		do	Do.
5.0	1.0	9.8	1,350	680	50		Fair	Cloudy.
5.0	2.0	9.2	1,350	1,070	21	33	do	Do.
	Zinc chloride							
6.0	2.0	11.7	1,640	385	77		Good	Clear.
6.0	4.0	11.7	1,730	470	73	75	do	Do.

[1] 1 pound of carbon added prior to lime addition.
[2] 0.35 pound of carbon added prior to lime addition.

Tomato wastes have been found to be quite amenable to chemical treatment. A 1-day test at an Ohio tomato cannery gave the following results:

Waste.—Wash water only, 7,200 gallons per day.

Chemicals.—Ferrous sulfate, 840 parts per million. Lime, 280 parts per million. Orifice box feed.

Mixing.—23 minutes, mechanical agitator.

Sedimentation.—2.3 hours. Sludge removed periodically and hauled to fields by truck.

Ponding.—Six ponds, 15-day detention. Cooling and condenser water (5,000 gallons per day) added and total flow passes through series of ditches to creek.

Analyses.—(See table Cn-3.)

	Raw	Settled	Ditch
Suspended solids, parts per million	1,910	562	41
Biochemical oxygen demand, 5-day, do	6,436	3,988	265

Remarks.—Ponding alone proved unsuccessful. Dry chemical feed and sludge removal mechanism recommended.

A Pennsylvania tomato-products plant has a chemical precipitation plant which has been in service since 1930.

Wastes.—All wastes from plant 375,000 gallons per day.

Fine screens.—North rotating screen, 40 mesh.

Chemicals.—Sodium aluminate, 50 parts per million. Lime, 640 parts per million.

Mixing.—11 minutes, baffled chamber.

Sedimentation.—Six and one-half hours. Sludge pumped from hoppers on first tanks to sludge field.

Analyses.—(Average 2 days:)

	Screened	Settled	Percent reduction
Settled solids .... cc./l..	28	2.6	91
Biochemical oxygen demand, 5-day .... parts per million..	300	165	45

An Ohio tomato-products plant built chemical precipitation waste treatment works in 1937. The details of this plant and the results of a test (by State of Ohio) on September 7 and 8, 1939, are as follows:

Design capacity.—One million two hundred thousand gallons per 20 hours (1,000 gallons per minute). September 7 and 8, 800,000 gallons per day (20,000 bushels per day tomatoes).

Pumps.—Four thousand eight hundred gallons wet well. Two 500 gallon-per-minute centrifugal pumps, float controlled.

Screens.—Two North fine (50 meshes per inch) rotating screens 6 feet diameter by 10 feet long. Screenings—to hopper, hoist, and trucks. Screen spray—100 gallons per minute recirculating pump.

Chemicals.—Lime feed machine—capacity 50 to 2,400 pounds per 24 hours. Ferric chloride feed machine—capacity 50 to 750 pounds per 24 hours. Control by float switches on pumps. Point of application, wet well. September 7 and 8, lime (hydrated) dose 24 pounds or 360 parts per million. Ferric chloride dose—460 pounds or 69 parts per million.

Flocculation.—8 feet by 33 feet by 10 feet 6 inches water depth, 20 minutes detention. Mechanical agitation—three sets of paddles (parallel to shaft on drum), on single horizontal shaft, 6 feet diameter, 10 feet long. Peripheral speed 2 feet per second.

Sedimentation.—Two tanks 16 feet by 63 feet 6 inches by 7 feet 9 inches water depth (flat bottom). Capacity—115,000 gallons. Detention—1.9 hours. Velocity—0.6 feet per minute. Sludge hoppers, two at inlet—6 feet 6 inches by 8 feet by 2 feet 6 inches deep. Capacity 130 cubic feet each. Sludge removal continuous, pumped to screenings hopper for truck disposal (on land).

Analyses.—(September 7:)

	Raw	Settled	Percent reduction
Suspended solids .... parts per million..	388	9	98
Total nitrogen .... do....	19	14	76
Biochemical oxygen demand (5-day, 20° C.)	830	392	53
Sewered population equivalent (based on biochemical oxygen demand)....	34,600	16,300	53

Experiments in Wisconsin indicated that plain sedimentation may be effective on tomato wastes. The wastes used in the experiments were rather weak (biochemical oxygen demand of screened wastes averaged 570 parts per million). Alum, sodium aluminate, zinc chloride, ferric chloride, ferrous sulfate, bentonite, and otaylite were used with lime. Alum showed the most favorable results. Plain sedimentation reduced the biochemical oxygen demand by 37 percent. Four pounds of lime and one pound of alum per 1,000 gallons of waste increased the efficiency to about 54 percent.

Eldridge found that treatment of tomato wastes with lime alone was as effective as treatment with lime and ferric chloride. The optimum amounts of lime were found to be from 800 to 900 parts per million (about 6.7 to 7.5 pounds per 1,000 gallons) when using fill and draw tanks with 4-hour sedimentation period. A 14-hour sedimentation period showed worse results because of gas formation in the sludge. When using a 2.5-hour detention period with a flowing-through tank the optimum lime dosage was about 1,000 parts per million (about 8.3 pounds per 1,000 gallons). Reductions in biochemical oxygen demand were generally from 40 to 50 percent.

TRICKLING FILTERS

Trickling filters have shown satisfactory results on the treatment of corn, pea, and tomato wastes. The fact that they require a considerable amount of time after the beginning of operation to attain full efficiency limits their usefulness. In general, the data indicate that after a suitable period of seeding trickling filter plants will accomplish over-all reductions of 50 to 85 percent in the biochemical oxygen demand of the screened wastes. Different experiments have not been in complete agreement on the allowable biochemical oxygen demand load per unit of filter area or volume. Various methods of pretreatment also have been used.

Corn canning wastes were treated on an experimental scale on a trickling filter at Canal Winchester. The media was ¼-inch–2-inch limestone and the filter was 6 feet deep. The only pretreatment was screening. The filter was dosed at a rate of 2,400,000 gallons per acre per day. After a suitable period of ripening, the filter reduced the biochemical oxygen demand of the raw screened wastes from 600 parts per million to 140 parts per million. Pennsylvania authorities report poor results with trickling filters on corn wastes. Both high rate and conventional types are in operation. The results, however, are not conclusive. Various changes have been suggested which may overcome the difficulties.

Tomato products wastes were treated experimentally at Bowling Green, Ohio. Some of the conclusions reached as a result of the study were as follows:

1. There was practically no lag between the time the trickilng filter treating tomato wastes was placed in operation and the time that typical purification efficiencies were obtained.

2. Typical trickling filter efficiencies with tomato wastes (with about 300 parts per million, 5-day biochemical oxygen demand) were as follows:

Biochemical oxygen demand removal percent

	Per cent
2.5 million gallons per acre per day	76
1.5 million gallons per acre per day	85
0.75 million gallons per acre per day	85
1.5 million gallons per acre per day [1]	78

[1] Equal parts sewage and tomato wastes.

In 1916 an experimental whole tomato waste treatment plant was operated at the Colter Canning Co., Amelia, Ohio, by the United States Public Health Service. The processes involved were sedimentation followed by filtration through cinder and sand filters in series. The details of this plant and test results after an initial operating period were as follows:

Sedimentation.—Imhoff tank.

Settling compartment: Adequate to be used as storage for complete equalization of flow throughout the 24 hours, or with a capacity equal to the maximum daily flow minus total gallons applied to filters during working day.

Sludge compartment (recommended): 1.2 cubic feet per 1,000 No. 3 cans (0.7 cubic feet per 1,000 No. 2 cans) per season.

Cinder filters, 4 feet deep (plus underdrain): Average rate 72,000 gallons per acre per day (75,000 gallons per acre per day recommended.)

Sand filters, 4½ feet deep (plus underdrains): Average rate 72,000 gallons per acre per day (75,000 gallons per acre per day recommended).

Sludge bed: Standard design 1.2 square feet per 1,000 No. 3 cans (0.7 square feet per 1,000 No. 2 cans) per season.

Biochemical oxygen demand, 5-days, 20° C.

Analyses—	Parts per million
Raw	4, 400
Settled	5, 000
Cinder filter effluent	1, 400
Sand filter effluent	Stable over 96 hours

Studies at Greenwood, Ind., during 1936 and 1937 indicated the practicability of high-rate trickling filters. Table Cn–6 shows operating data and average biochemical oxygen demand reductions.

TABLE Cn-6.—*Results of operations using chemical precipitation and 1-hour batch settling followed by high rate trickling filters*

Operating data	1936	1937
Rate return to filter	1–1	2–1
Filter rate [1]	30	30
Type waste	Tomato	Mixed vegetables [2]
Chemical dose per 1,000 gallons	5 pounds lime, 0.75 pounds copperas	5.3 pounds lime, 1.8 pounds copperas
Biochemical oxygen demand (parts per million):		
Raw screened wastes	915	1,191
Primary effluent	599	678
Filter effluent	277	489
Secondary effluent	230	370
Percent reduction	75	69

[1] Million gallons per acre per day.
[2] Tomato, corn, lima bean, green bean, carrots, and mixed vegetables

Among the conclusions reached were—

(1) Lime and copperas are the most efficient coagulants available at the present time. For the best results the pH should be about 8.4. Larger amounts of coagulants than those shown above gave considerably better results. Thorough mixing of the coagulants is necessary.

(2) Air should enter the filter both at the top and bottom. A blower is necessary to force the air up through the bottom. At least 2 weeks' time is required to build up the growth on the media.

(3) Small sized filter media (1 inch 2½ inch) cannot be used in high rate filters on cannery wastes. The filter equipped with media ranging from 2½ inches to 4 inches did not clog when being operated at a high rate.

(4) The increased efficiency of the high rate filter when operating at a return ratio of 3 to 1 rather than a return ratio of 1 to 1 does not apparently justify the additional cost.

(5) Sludge may be at least partially dried on ordinary sludge drying beds. After about 6 days the pasty sludge can be removed by shoveling. A large percent of the sludge, especially that from the green bean, lima bean, beet, carrot, and mixed vegetable waste was due to the addition of the copperas and lime.

Studies in Wisconsin using a high rate stone filter 8 feet deep with 2½-inch–3-inch media and a tile filter 7.5 feet deep treating screened corn and tomato wastes showed the results shown on table Cn–7.

TABLE Cn–7.—*Results obtained by high rate trickling filter treatment of corn and tomato wastes*

Item	Unit	Corn waste		Tomato waste	
		Tile filter	Stone filter	Tile filter	Stone filter
Dosage	Million gallons per acre per day.	26.7	21.4	24.4	12.8
Recirculation	Percent	70	69	None	None
Settling tank detention	Minute	26	47	28.0	78.5
Sampling period	Hour	3.5	3.5	6	6
5-day biochemical oxygen demand:					
Raw	Parts per million.	1,660	1,660	850	850
Filtered	do	980	730	740	370
Settled	do	760	510	530	370
Total biochemical oxygen demand reduction:					
Filtered	Percent	41	56	12	56
Settled	do	54	69	38	56

Data obtained from these studies are too limited to permit accurate generalization.

Pea wastes were treated on a conventional trickling filter at Albion, N. Y., in 1928 and 1929. The filter was 8 feet deep, the media 1½-inch–2¾-inch crushed limestone. A 20-mesh screen was the only pretreatment. The first three columns of table Cn–8 summarize the results of the experiments. The last column shows the results of tests on the filter installed as results of the experiments. The depth of the filter is unknown. It was built in an abandoned quarry and is thought to vary between 8 and 20 feet in depth.

TABLE CN–8.—*Treatment of pea cannery wastes on trickling filters at Albion, N. Y.*

Item	Unit	Experiment			As installed
		1	2	3	
Dosage	Million gallons per acre per day.	1.96	0.98	0.58	1.82
5-day biochemical oxygen demand:					
Screened	Parts per million.	713	1,157	1,715	1,880
Filtered	do	453	509	400	703
Reduction	Percent	36	52	79	65

The high rate filters used in the Wisconsin studies of corn and tomato wastes were also used in treating wastes from pea canning. After 15 day's conditioning, the results shown on table Cn–9 were obtained.

TABLE CN–9.—*Results obtained by high rate trickling filter treatment of pea canning wastes*

Item	Unit	Tile filter			Stone filter		
		Date					
		July 12	July 15	July 16	July 12	July 15	July 16
Dosage	Million gallons per acre per day.	20.0	20.0	20.0	20.0	20.0	20.0
Recirculation	Percent	63	63	63	63	63	63
Settling tank detention	Minute	34	34	34	50	50	50
Sampling period	Hour	7.5	8	10	7.5	8	10
5-day biochemical oxygen demand:							
Raw	Parts per million.	660	1,670	1,690	660	1,670	1,690
Filtered	do	530	1,140	1,170	410	860	700
Settled	do	470	1,100	610	480	650	1,400
Total biochemical oxygen demand reduction:							
Filtered	Percent	19	32	31	37	49	59
Settled	do	29	34	64	28	61	23

INTERMITTENT SAND FILTERS

Relatively little information is available on the efficiency or suitability of this device for treating cannery wastes. Studies at Canal Winchester on wastes from corn, succotash, and lima-bean canning showed good results. The filters consisted of 30 inches of sand (effective size 0.27 millimeter, uniformity coefficient 2.3) over 6 inches of torpedo sand, and 6 inches of graded gravel. Table Cn–10 shows the results of the experiment.

TABLE Cn–10.—*Results of intermittent sand filtration of corn, succotash, and lima-bean wastes*

Dosage rate	Screened wastes		Effluent from sand filters: 75,000 gallons per acre per day		Effluent from sand filters: 100,000 gallons per acre per day	
Date	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids
Sept. 3, 1926			112	20	140	10
Sept. 10, 1926	533	228	28	32	27	40
Sept. 13, 1926	344	344	59	34	54	26
Sept. 17, 1926	581	267	31	40	53	60
Sept. 21, 1926	455	290	22	80	16	40
Oct. 1, 1926	200	383	23	4	37	4
Oct. 7 1926	175	460	0	40	0	52

Siebert says: "Wastes from a Pennsylvania cannery packing whole-kernel corn have been treated with promising success in a plant providing fine screening, 1-hour plain sedimentation, intermittent sand filtration at a rate of about 100,000 gallons per acre-day, and drying of settled solids on a sludge bed having an area 10 percent of the intermittent sand filters. An efficiency of 85 percent in reduction of biochemical oxygen demand (raw biochemical oxygen demand average 4,900 parts per million) was measured in this plant but the two filters finally became matted with starch jelly which would not dry rapidly enough for removal. One additional filter (50 percent increase in present filter area) would probably make the treatment plant sufficiently flexible to operate successfully over the entire 5 or 6 weeks of the corn canning season, but it is doubtful if treatment of this type would be suitable for strong full-line cannery wastes over a long season because of cumulative clogging of the filters without sufficient rest periods for decomposition of the clogging materials."

TREATMENT WITH MUNICIPAL SEWAGE

From the standpoint of the cannery, this is the simplest method of waste disposal. It may also be the most economical method since the incremental cost necessary to provide treatment in the municipal treatment plant may be less than the cost of building and operating an independent treatment plant for the cannery waste. From the standpoint of an agency administering pollution-abatement laws, this method is desirable since it centralizes responsibility for proper operation of treatment works.

Since the methods of treating cannery wastes are similar to those for sewage treatment, it should be possible, at least theoretically, to treat a mixture of cannery wastes and sewage in almost any proportion if the plant is properly designed and operated.

The municipal treatment plant at Celina, Ohio (population 4,841) treats cannery wastes with a population equivalent of about 18,000 in addition to wastes from a large creamery. The plant is of the activated sludge type with chemical pretreatment at the municipal plant. The wastes are screened at the cannery and chemical dosage is regulated by the treatment-plant chemist on the basis of daily reports from the cannery as to the amounts of various products to be canned. These products include peas, beans, beets, tomatoes, hominy, and spaghetti. The coagulants used are lime and either ferrous or ferric sulfate. Table Cn–11 shows the results obtained during the last 6 months of 1940, during which time the cannery operated all but 31 days.

TABLE CN–11.—*Monthly average results of treatment of sewage, cannery waste and milk wastes at Celina, Ohio, municipal treatment plant, 1940*

[Results in parts per million]

Month	Waste flow million gallons per day	Biochemical oxygen demand			Suspended solids		
		Raw	Treated	Percent reduction	Raw	Treated	Percent reduction
July	0.408	1,500	23	98.5	352	13	96.3
August	.480	1,037	58	94.6	591	32	94.6
September	.438	865	37.2	95.7	445	67	85.0
October	.399	840	20.2	97.6	510	22	95.7
November	.370	790	21.2	97.3	550	21	96.2
December	.420	463	38.2	91.7	402	56	86.1

The municipal treatment plant at Yakima, Wash., providing primary treatment treats cannery wastes equivalent in suspended solids to 165 percent of the domestic sewage load. No operating difficulties are reported and removals of 55.3 percent of the suspended solids and 43.8 percent of the biochemical oxygen demand are obtained when treating the combined sewage and industrial waste.

In addition to these, there are many other municipal treatment plants successfully treating cannery wastes which place much heavier biochemical oxygen demand loadings on the plant than the ordinary municipal sewage. Careful operation, including coordination of treatment plant operation with cannery operation, and adequate design are necessary if satisfactory results are to be obtained. Chemical treatment, either at the cannery or at the municipal plant, is usually desirable if biological treatment is provided.

Studies of the efficiencies of four Wisconsin sewage treatment plants treating cannery wastes which had been pretreated by chemical precipitation at the cannery showed that both trickling filters and activated sludge plants can treat these wastes effectively if the biochemical oxygen demand load is not too heavy. All of the plants were overloaded during peak canning operations and plant efficiencies were reduced by these overloads but all of the plants recovered within a short time after the cessation of canning. The report on these studies concluded:

"Municipal treatment plants of the trickling filter type should be of sufficient size to provide a minimum of 80 cubic feet of filter media per pound of 5-day biochemical oxygen demand per 24 hours to maintain a high degree of efficiency during peak cannery loads. A finishing sand filter provides substantial additional treatment. Activated sludge plants receiving sufficient cannery waste to produce a sludge index in excess of 200 may be expected to cause bulking and other operating difficulties."

COSTS

The cost of cannery waste treatment plants has been estimated by Warrick, et al., as follows:

Type of treatment	Size cannery	Capital cost	Daily cost	Cost per case
	Cases per day			
Chemical precipitation	2,000	$3,000	$19.10	$0.01
Do	5,000	5,000	33.85	.007
Trickling filters	2,000	13,000	29.80	.015
Do	5,000	16,000	37.45	.0075

These estimates are based on assumptions of 25 gallons of waste per case, a treatment plant life of 20 years, an annual operating season of 50 days, and interest at 5 percent. The trickling filter plants do not include chemical precipitation. The daily costs include allowances for depreciation and interest.

The Indiana State Board of Health estimated that a plant providing chemical treatment and high rate filters for a cannery waste flow of 100,000 gallons per day would cost about $8,000. Operation and maintenance were estimated at $19 per day, including labor, chemicals, power, and maintenance.

Nitrate treatment to lagooned pea wastes was estimated by Sanborn to cost about \$0.004 per case. This is based on a biochemical oxygen demand of 1,500 parts per million. The cost of lagoons varies so much with local conditions that no general figure can be given.

TREATMENT PLANT DESIGN

Regardless of how the wastes are disposed of, there is general agreement that fine screening is essential. Forty-mesh screens have proved satisfactory, although coarser screens (20-28 mesh) are sometimes used. They may be either of the rotating or vibrating type, should be equipped with a continuous strong water spray (about 40-60 per square inch pressure). A steam cleansing once a day is useful to prevent slime growths. At least 1 square foot of screen area should be provided for each 200 gallons of waste per hour. A bar rack or coarse mesh bucket screen is desirable ahead of the fine screen to intercept the coarsest material and to prevent damage to the screen.

Fill and draw chemical precipitation tanks should provide at least 1 hour of quiescent sedimentation. Addition of chemicals and mixing require an additional 15 to 20 minutes. In continuous flow plants the coagulation basin should provide about 15 minutes detention and the sedimentation basin about 90 minutes detention. Hopper bottom tanks are generally used because of their lower first cost than tanks equipped for continuous sludge removal. The hoppers should have a slope of not less than 45 degrees. Round tanks are preferable to square ones, particularly for fill and draw operation, since they facilitate thorough mixing and sludge removal.

The available data on trickling filter performance with cannery wastes are not conclusive enough to permit any positive general statements regarding permissible biochemical oxygen demand loadings. Various experiments indicate that the strength of the applied waste, the type of pretreatment, the pH of the applied waste, the size of the filter media, and the ventilation of the filter have important effects on the efficiency of trickling filters. Stone of $2\frac{1}{2}$ inches minimum size has been found most satisfactory. Biochemical oxygen demand removals in secondary settling tanks seem to be higher in cannery waste treatment plants than in sewage treatment plants. Efficiencies comparable to those of trickling filters treating domestic sewage probably require about the same volumes of filter media but much higher loadings can be applied at a sacrifice of efficiency.

Sludge beds for drying sludge from the chemical precipitation tanks dries readily in a week or less. About 3,000 square feet of drying beds are required per 100,000 gallons of waste per day. The beds should be about 12 inches deep with 6 inches of sand on 6 inches of graded gravel. Underdrains should be provided as in any sludge-drying bed.

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Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–2

INDUSTRIAL WASTES (Not an actual cannery)

River Mileage Index No. *MiMa–130.8*

Type of Plant: *Tomato Cannery.* State: *Ohio.*
Name of Plant: *West Liberty Canners.*
Municipality: *West Liberty.* Main Watershed: *Miami.*
County: *Logan.* Sub-Watershed: *Mad River.*
Address: *West Liberty.*
Source of Information: *J. L. Dee—Supt. & Owner.*
Plant Operation:
Average;
60 hours per week—30 days/year.
100 employees plant—3 office.
Maximum;
72 hrs. per week—10–12 days/year.
110–115 employees plant—3 office.
Seasonal Variation: *Operate from Aug. 10–15 to Oct. 1–10 or until killing frost.*

(Survey report continued on next page)

Survey by *E. P. Brown.* Date: *8–24–39*

Sewered Population Equivalent Computation:
Factors used *per case of No. 2 cans* (*or per bushel*) *per day:*
B. O. D.: *1.5.* Suspended solids: *0.6.*
Sewered population equivalent based on B. O. D.: *3,000.*
Sewered population equivalent based on suspended solids: *1,200.*
Remarks: *Due to care in plant, estimates of sewered population equivalent may be higher* (*possibly 20 per cent*) *than actual.*
Compuation by: *John Jones.* Date: *Sept. 12, 1939.* Cincinnati Office.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

(*Typical inspection report continuation sheet*)

West Liberty Canners. MiMa–130.8

Water supply.—Municipal supply and private well. Municipal supply used only when well is inadequate.

	Gallons per day		
	City	Well	Total
Average	3,000	12,000	15,000
Maximum	8,000	12,000	20,000

Boiler water softened—no other treatment.

Well: 6-inch casing, 120 ft. deep, gravel, 20 g. p. m. turbine pump.

Products Canned—Chiefly whole tomatoes:

Average 60,000 cases No. 2 cans per year (including 4,000–5,000 cases puree and juice).

1937—75,000 cases No. 2 cans.

1938—50,000 cases No. 2 cans.

1939—50,000 cases No. 2 cans (expected).

Normal daily pack 2,000 cases.

Wastes: Ave. 15,000 g. p. d. estimated from pump capacity and water bills.

Skins, cores, etc. hauled to farm land.

Filler may overflow occasionally.

Bar screen on outlet. No analyses.

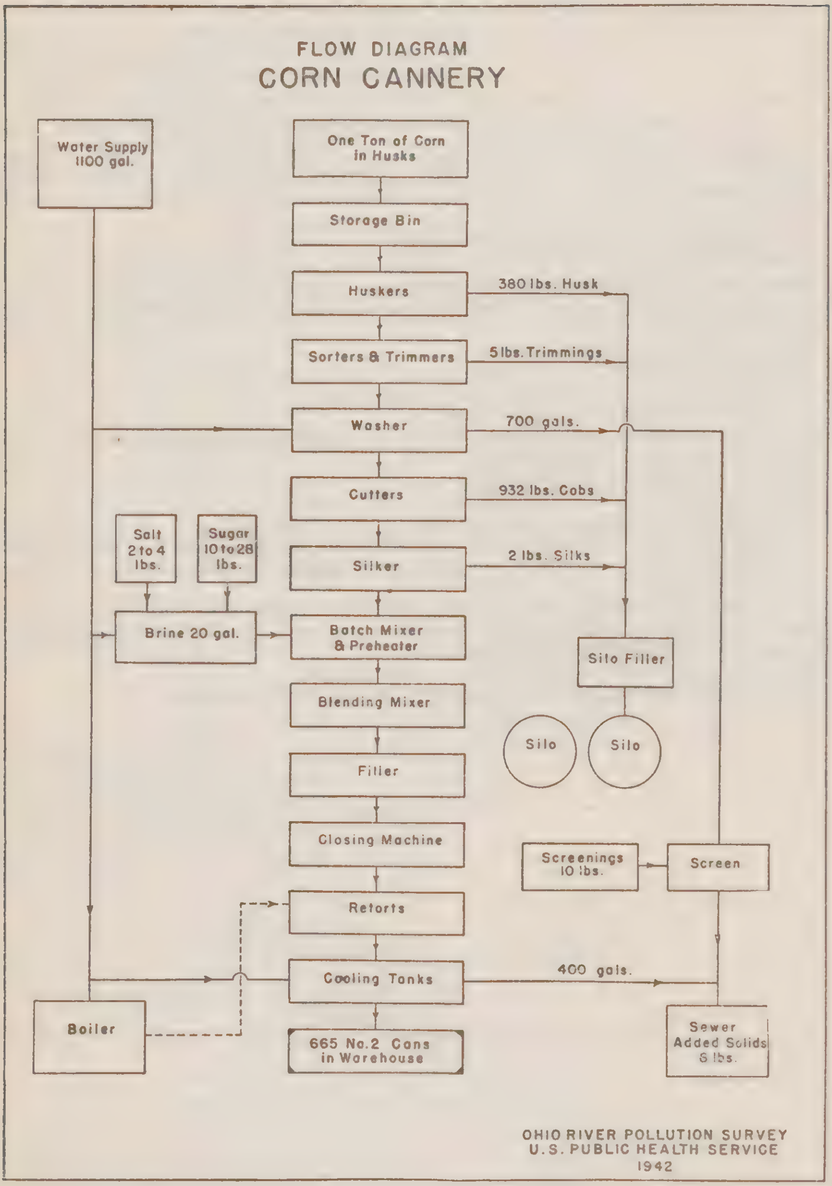
Appearance—reddish. Visible solids.

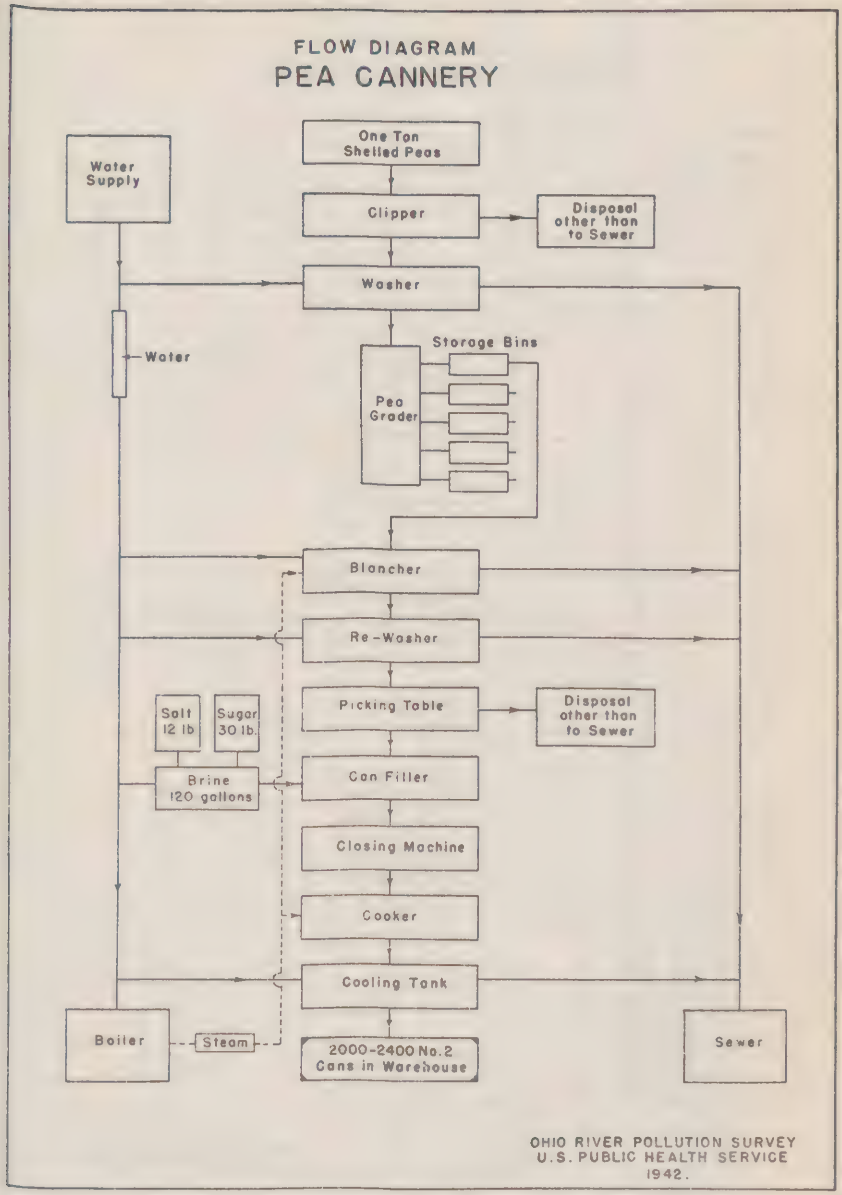
Segregation of strong wastes: None except as noted. Practice of disposal of concentrated material, spills, etc. on farm land could be extended without difficulty.

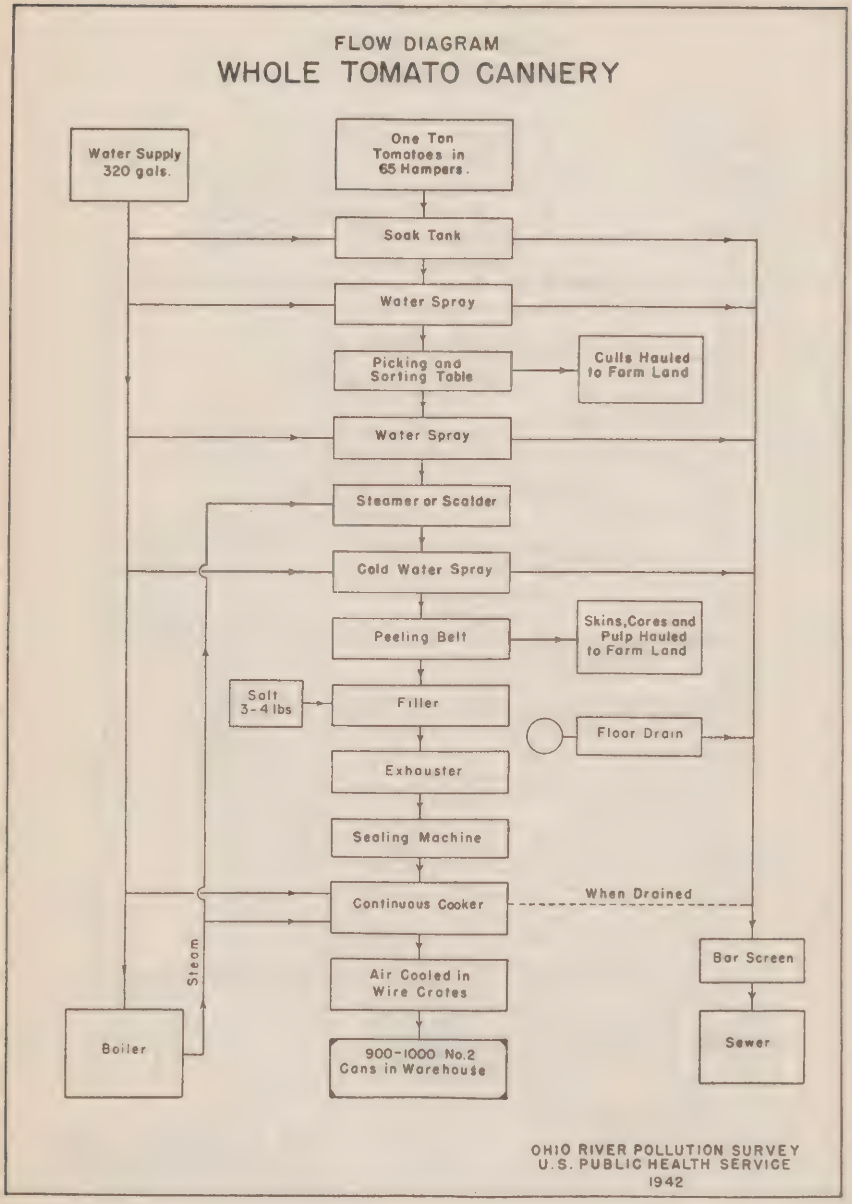
Outlet: to narrow ditch to Mad River. 10-inch circular V. C. tile south from plant. For gaging weir could be installed in ditch. Red color below outlet. Deposits in ditch and along bank of river.

Sanitary sewage: 6-inch sewer to river. Also privies.

Remarks: Housekeeping methods appear to be better than average.


FLOW DIAGRAM
CORN CANNERY
Water Supply 1100 gal.
One Ton of Corn in Husks
Storage Bin
Huskers
380 lbs. Husk
Sorters & Trimmers
5 lbs. Trimmings
Washer
700 gals.
Cutters
932 lbs. Cobs
Salt 2 to 4 lbs.
Sugar 10 to 28 lbs.
Silker
2 lbs. Silks
Brine 20 gal.
Batch Mixer & Preheater
Silo Filler
Blending Mixer
Silo
Silo
Filler
Closing Machine
Screenings 10 lbs.
Screen
Retorts
Cooling Tanks
400 gals.
Boiler
665 No. 2 Cans in Warehouse
Sewer Added Solids 5 lbs.
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942


FLOW DIAGRAM
PEA CANNERY
One Ton Shelled Peas
Water Supply
Clipper
Disposal other than to Sewer
Washer
Water
Storage Bins
Pea Grader
Blancher
Re-Washer
Salt 12 lb
Sugar 30 lb.
Picking Table
Disposal other than to Sewer
Brine 120 gallons
Can Filler
Closing Machine
Cooker
Cooling Tank
Boiler
Steam
2000-2400 No. 2 Cans in Warehouse
Sewer
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942.


FLOW DIAGRAM
WHOLE TOMATO CANNERY
Water Supply 320 gals.
One Ton Tomatoes in 65 Hampers.
Soak Tank
Water Spray
Picking and Sorting Table
Culls Hauled to Farm Land
Water Spray
Steamer or Scalder
Cold Water Spray
Peeling Belt
Skins, Cores and Pulp Hauled to Farm Land
Salt 3-4 lbs
Filler
Floor Drain
Exhauster
Sealing Machine
Continuous Cooker
When Drained
Steam
Air Cooled in Wire Crates
Bar Screen
Boiler
900-1000 No.2 Cans in Warehouse
Sewer
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

CANNERY WASTES (Not an Actual Cannery)

Plant West Liberty Canners State Ohio Ref. No. Mi Ma-130,8

City West Liberty County Logan Main Watershed Miami River

Address West Liberty, Ohio Sub-watershed Mad River

Informant J. L. Doe Title Supt. & Owner Principal Product Whole Tomatoes

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	60	30	100-110
Maximum	72	10 to 12	110

Seasonal variation Operate from Aug. 10-15 to Oct. 1-10 or Killing Frost

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	Municipal	3,000	8,000	Boiler Water
Industrial	Well	12,000	12,000	Softened
Cooling	Total	15,000	20,000	

PRODUCTS CANNED:- Ave. 60,000 Cases No. 2 Cans Whole Tomatoes per Year Including 4,000 to 5,000 Cases Puree and Juice

Normal production, height of season 2,000 Cases per day

WASTES:- Quantity 15,000 How estimated Water Bills & Pump Capacity

Washing 15,000

Other

Disposal other than water carried Skins, Cores etc. Hauled to Farm Land

Possible spills Filler may Overflow Occasionally

Segregation of Strong Wastes None except as above

Difficulties None for Extension of Disposal on Farm Land

Treatment Fixed Bar Screen

Analysis:- Number None Date By whom

OUTLET:- Where to Ditch to Mad River

Description:	Size and Shape	Material	Location	Elevation
1.	10 inch. Circular	V.C. Tile	South from	
2.			Plant	
3.				

Gaging possibilities Weir Possible in Narrow Ditch

Conditions below outlet: Color Red

Turbidity Deposits in Ditch and along Bank of River

SANITARY SEWAGE: Disposal Privies and 6" Sewer to River Persons tributary 100-125

REMARKS Housekeeping Methods Better than Average. Packing: 1937-75,000 Cases. 1938-50,000. 1939-50,000 (Expected) Well: 6" Casing, 120' Deep Gravel-Turbine Pump 20 g.p.m.

Survey by E. P. Brown Date 8-24-39

APPENDIX III OF SUPPLEMENT D

COAL WASHERIES

An Industrial Waste Guide to the Coal Washery Industry

CONTENTS

LIST OF TABLES

Abstract

The coal-washing process consists of the separation and removal of noncombustible material to produce a superior product with a uniformly low ash content. This result has been most generally accomplished by the use of hand picking and pneumatic, magnetic and hydraulic machines.

Hand picking of coal with disposal of rejected material to fills and dumps starts at the coal face. Pneumatic and magnetic separation is attained by use of air and magnetized belts or rolls. The impurities collected are again deposited chiefly in fills or dumps, although magnetic separation may yield material of value.

Hydraulic methods of separation depend on specific gravity differences. Water is generally used, although oils and solvents have served and these are sometimes used in conjunction with water. Water, acting as a carrier of the impurities, has been either discharged directly or passed through recovery equipment, and conditioned for reuse. Sludge from the wash water consists of fines and culm, which, after proper reduction of moisture content, may be discharged to dumps, mixed with other sizes to regulate ash content, or shipped separately for stoker consumption.

Nuisances and complaints resulting from the discharge of wash waste to the stream are generally due to the presence of solids or sludge. Dumps and fills not intelligently located, may contribute considerable quantities of solids by bank erosion or seepage through the refuse. The resulting deposits on the bottom and along the stream banks impair recreational facilities, damage sand and gravel qualities and reduce the general appearance of the stream to an unattractive black streak. The solids blanketing the stream beds no doubt have a destructive influence on fish food.

Present limited available information indicates that oxygen requirements of washery wastes are of minor consequence. Acids contributed to streams from sludge and gob piles, through underdrainage, have at times become serious.

Objectionable pollution from coal washeries can generally be eliminated by sedimentation and reuse of water in a closed system. These methods are practiced at a number of washeries, either to correct pollution or because of a necessity to conserve water.

Sludge and gob pile contribution to stream pollution can be materially reduced, if not completely eliminated, by proper selection of location and systematic drainage through open ditches or covered waterways.

General Information

The practice of washing coal developed many years ago in England, France, and Germany, and many of the methods employed today in this country were developed in foreign coal fields. Coal washing usually is taken to mean more than separation of coal from dirt or impurities by use of water. Many practices today employ the use of dry methods to accomplish the same purpose, all of which are spoken of as "washing" coal. Although statements in this guide refer to bituminous coals, those statements, in most cases, are applicable to the anthracite industry as well.

Coal cleaning equipment and facilities are generally housed near the mine entrances. The general name applied is usually "preparation plant" and includes the sizing, and car and truck loading machinery, as well as the washery. This name, however, is not accepted in all coal mining fields. In Kentucky, the preparation plant is spoken of as the tipple and washery, while it is understood that this same combination in the anthracite fields of Pennsylvania is spoken of as the colliery or breaker.

The preparation plant consists of: (1) Crushers for breaking the coal down to the desired sizes, (2) screens for separating these sizes to the required fractions, (3) the washery for separating the impurities from the coal, (4) recovery, machinery for reclaiming coal from water, (5) inspection conveyors, (6) driers, (7) oilers, and (8) loading and handling machinery. Waste-treatment facilities may also be mentioned here as part of an up-to-date plant but not all operations include this refinement.

Impurities in coal consist of shale, clay, pyrite or marcasite, calcite, and gypsum, all of which, except the clays, are usually found in the beds. The clays may make up the roof or floor of the mine and, although they are separated from the raw coal as to position, it is difficult to extract the coal free from clay, especially if carelessly handled.

Impurities combined with the carbon and spoken of as fixed structural impurities consist of mineral matter, part of which is inherent sulfur, prevalent in the vegetable deposits forming the coal. These cannot be removed by washing and, therefore, washing is limited to some extent in purifying the coal.

Many of the industries of today employing the use of coal require it to be of specified sulfur content. The metallurgical and ceramic products industries are typical of those requiring such regulation. The American Society for Testing Materials has set up the following regulations pertaining to limitations of sulfur content of coal used in the manufacture of various products:

Product	Maximum sulfur content of raw coal
	Percent
Blast furnace coke	1.3
Foundry coke	1.0
Ceramic products [1]	1.3

[1] Discoloration is the governing factor and sulfur content depends upon the products manufactured.

High sulfur content is objectionable for use in power plants where, if burned with high moisture content, it increases the corrosive action of the flue gases.

Ash-forming impurities such as clays, shale, etc., reduce the ultimate value of the fuel. Two other impurities generally associated with coal are pyrite and marcasite, which are also ash-forming impurities. They are the source of iron and are further objectionable in forming clinkers.

The general advantages of washing and cleaning coal are: (1) increased sales and price, (2) increased heat value, (3) maximum useful application of heat evolved, and (4) elimination of freight and cumulative handling costs on refuse. High quality coal is demanded by the consumer, and the producer is required to meet this demand. Methods used are first governed by the condition of the raw coal. Some coals require only crushing and screening into sizes; others require screening, mechanical cleaning and hand picking. The best preparation requires all steps previously mentioned, plus additional refinement by dry or wet processing. As a rule, the maximum refinements demand the maximum price, although this is not altogether true. Steel companies and private consuming industries who mine their own coal institute refinements to secure a fuel to fit their own particular needs. Nearly all anthracite fuel is cleaned and washed.

Many improvements have been made and developed since the cleaning of coal began. As a result, waste of this fuel is reduced and the finished product is of higher quality. Refinements and improvements in methods have made it economical to rework old refuse piles in the anthracite fields.

Description of Coal-Washing Processes

As has been previously stated, coal washing is a term generally applied to the cleaning of coal. The methods used are many, several of which may be practiced at the same plant. The first two always used are mine and breaker picking and screening. Screening and breaker picking often are preceded by crushing to reduce to the desired fractions, and screening may be resorted to between other operations which might follow.

MINE AND BREAKER PICKING

Mine and breaker picking are carried out by the miners and employees in the cleaning plant. As the coal is blasted or dug from the beds preparatory to being loaded in cars, many impurities, such as shale, present themselves in large masses. These are singled out by the miner and detoured to the refuse dumps. As the coal moves through the preparation plant on metal or rubber conveyors, employees are stationed nearby to pick out the impurities, with discharge to refuse piles. These practices reduce considerably the impurities in the coal in many cases, and lessen the load on other processing which follows.

SCREENING

Screening is followed by all preparation plants and consists of separating the coal into various sizes from 6-inch to very fine, according to the desires of the operator or suitable to the demands of the consumer. Some coals with high ash content are only retained down to a certain small size. Fractions below this size are discarded to dumps. Screening is often necessary preceding many of the processes which follow in the preparation plant.

AIR CLEANING

Air is used in the preparation plant for cleaning. Dedusting is sometimes practiced on coals before going through the washery. This amounts to nothing more than a stream of air directed through a screen to carry away the lighter clays, etc., which are usually caught in a cyclone hood and discharged to the dump.

WET PROCESSES

Wet processes of washing and cleaning coal are accomplished by the use of (1) trough washers, (2) launders, (3) piston and pan jigs, (4) rising current classifiers, and (5) table concentrators. These machines all use the gravity stratification principle and are similar to the air classifiers, except that the medium employed is water. In all cases the coal and water must be kept in a mobile state by either continuous discharge of water or swelling of the moving mass as in the piston jigs.

The disadvantages of this method are, first, the wash water must be disposed of to the stream or purified for recirculation and, second, the product picks up considerable moisture and requires drying.

On emerging from the washers, screening classifies the larger coal over about the three-sixteenths-inch size. The larger fractions are routed to storage or cars unless tests prove that further breaking down of the coal to free more impurities

will prove economical. In this case the products receive further crushing and are returned to the washer. The fines or fractions below the three-sixteenths-inch size are discharged with the water either to the stream, to ponds, or to settling tanks. More generally settling tanks are used, whereby these fines can be reclaimed and sold for stoker fuel or mixed with the larger sizes for building up ash content. In preparation of stoker fuel it is necessary to reduce the moisture content and this is accomplished by means of centrifugal driers.

Settling tanks for recovery of fines are equipped with drag conveyors which are continuously operated. The effluent is either discharged to the stream, returned to the washer, or passed on for further purification before entering the washer or being discharged to the stream. In closed systems, water is never discharged, and make-up water to take the place of natural evaporation or moisture carried out in the coal or refuse material is generally supplied through the final spray of a series used on the finished product.

Refuse material from the washers is usually disposed of on dumps 'and fills. In the case of table-type washers, valuable pyrite may be salvaged as a byproduct.

Other wet processes involving the specific gravity principle include sand, clay, zinc chloride, calcium chloride, and magnetic flotation. Any of the first five of these are combined with water to produce a medium of increased specific gravity, whereby impurities can be separated for the desired result. In magnetic flotation, magnetized conveyors, plus the buoyancy of water, separate the impurities. In all cases the difficulty of separating the coal from the water and cleaning the effluents is a disadvantage.

Wet processes of the nongravity type include froth flotation and the recently introduced oil amalgam type (Trent process).

MAGNETIC PROCESSES

Many plants use magnetic belts or rolls, in addition to other cleaning equipment, to separate "tramp" iron from the coal. These facilities generally precede other operations and considerably reduce the load to the main plant.

Other processes which might be mentioned include sand flotation and electrostatic separation. These do not involve the use of water although the first comes under the float-and-sink group and depends upon the specific gravity of the raw product to separate out in a bed of sand. Electrostatic separation is of the nongravity type, and while it can be used on coal it is best suited for cleaning ores.

OILING

Although oiling of coal may not be considered a cleaning step, yet to some degree it accomplishes that purpose. It settles the dust in the coal and prevents excessive cleavage and breakage. It is applied to the coal through high-pressure sprays, in quantities to meet the demands of the consumer. Reported quantities used are 5 to 6 quarts per ton of coal.

TABLE Cw-1.—*Bituminous coal cleaned, 1935–36, by classes of equipment (central washery plants operated by consumers in Colorado and Pennsylvania included)*

Type of equipment	Plants in operation		Net clean coal (million tons)		Percent cleaned by each type	
	1935	1936	1935	1936	1935	1936
Wet methods:						
Jigs	138	154	15.7	23.4	34.7	38.3
Concentrating table [1]	9	8	1.1	1.8	2.5	3.0
Jigs combined with concentrating tables [1]	15	16	1.5	2.6	3.4	4.3
Launders and upward current classifiers	93	98	18.4	22.6	40.7	37.1
Total, wet methods	255	276	36.9	50.5	81.3	82.7
Pneumatic methods	65	66	8.5	10.6	18.7	17.3
Grand total	[2] 320	[2] 342	45.4	61.1	100.0	100.0

[1] A more representative figure for the use of wet tables is indicated by combining the totals for concentrating tables with the total for jigs used with concentrating tables. This shows a net gain of 1.8 million tons (67.1 percent) for 1936.

[2] Plants using both wet and pneumatic types: 32 in 1935; 31 in 1936.

TABLE Cw-2.—*Total production of all bituminous coal at mines with cleaning plants, 1935–36, in net tons*

[Does not include any estimate for mines that may ship to consumer-operated plants]

	Millions of tons	
	1935	1936
Wet methods:		
Jigs	34.9	49.0
Concentrating tables	1.5	1.2
Jigs in combination with concentrating tables	1.8	2.8
Launderers and upward-current classification	37.8	47.9
Total wet	76.0	100.9
Pneumatic methods	24.0	30.0
Grand total	100.0	130.9
Less duplication [1]	12.8	15.5
Net total	87.2	115.4
United States production of bituminous coal	372.4	439.1
Percent produced at mines with cleaning plants	23.4	26.3

[1] Mines using both wet and pneumatic methods.

PLANT OPERATION

The average operating time of a preparation plant is 7 to 9 hours daily although some plants require 20 hours maximum. This depends upon the capacity of plant, sizing of product, refinements followed, condition of raw coal, and efficiency of equipment. Records are available on washing plants with capacities ranging from 150 to 8,500 tons per day. Many plants prepare for market a good portion of the coal produced by crushing and screening, with the balance going through the "washery." It is therefore difficult to set up any comparative cost schedule in lieu of variations which seem to exist. Records are available to show that installation costs vary between $500,000 and $1,800,000 per 1,000 ton-hour capacity, including complete treatment of slurry, and that this treatment installation cost averages around 2 to 5 percent of total investment.

Employees required to operate a preparation plant depend upon the activities in the plant itself. As most mechanical operations are controlled from one panel, one employee in the "washery" is sufficient to handle a good-sized plant. Picking and loading operations influence the number required for the plant as a whole. Available information indicates that 12 to 20 employees are required to operate plants from 500 to 1,000 ton-hour capacity.

Cost of cleaning fine anthracite with jigs and tables is shown in table Cw-3 in cents per ton (by Hobart):

TABLE Cw-3.—*Cost of cleaning fine anthracite*

Item	Cost in cents per ton	
	Jigs	Tables
Maintenance and operation	3.60	1.27
Power	.47	.15
Depreciation	.20	1.20
Water supply	.26	.13
Total (cents per ton)	4.53	2.75

RAW MATERIALS AND PRODUCTS

Run-of-the-mine coal contains many impurities, some of which can be easily separated while others give considerable trouble and increase the facilities necessary for handling. The "R. O. M." (run of the mine) may vary considerably from one day to the next so that it is impossible to set up any relation between raw material and product.

The ash content in the finished product is generally maintained by mixing fines (high in ash) with the sized coal. A typical analysis of coal in various classes is shown in table Cw–4.

TABLE Cw–4.—*Typical analyses of raw and cleaned coal, and discarded refuse*

	Raw coal, 100 percent	Cleaned coal, 94.59 percent	Refuse, 5.41 percent
Volatile matter	18.60	18.65	12.09
Fixed carbon	72.45	74.75	34.91
Ash	8.95	6.60	53.00
Total	100.00	100.00	100.00
Sulfur	.84	.83	1.20

Some localities have coal mines sufficiently high in pyrites to warrant operation of washeries to recover this material. This operation is generally accomplished by the use of concentration tables.

A record of operation of a refuse plant is here given:

TABLE Cw–5.—*Operation records on a coal refuse salvage plant*

Year	Days	Men	Coal salvaged, in tons	Pyrite produced, in tons
1937	266	15	42,052	15,000
1938	320	24	39,950	17,757
1939	183	26	4,494	11,018

Refuse produced at preparation plants is discharged to dumps and fills, generally along the bed of a stream. Refuse produced amounts to between 4 and 5 percent of cleaned coal production for the country as a whole. Some plants, giving little or no treatment to washery wastes, discharge them through drilled holes to old mine workings.

TABLE Cw–6.—*Relation in 1936, by States, between total bituminous coal production, amount cleaned, and results from cleaning operations*

Bituminous production by States	Total production of mines with cleaning plants (millions of tons)	Result of cleaning operations (millions of tons)			Percent of refuse to raw coal	Percent of clean coal to total mine production
		Coal cleaned	Clean coal	Refuse		
Alabama	11.14	11.12	9.92	1.20	10.8	89.1
Colorado	(1)	(1)	(1)	(1)	8.5	26.6
Illinois	17.19	6.67	5.61	1.06	15.9	32.7
Indiana	4.85	2.56	2.20	.36	14.0	45.3
Kentucky	2.50	.56	.51	.05	8.9	20.6
Missouri and Kansas	2.35	2.05	1.77	.28	13.7	75.4
Ohio and Michigan	2.88	1.54	1.33	.21	13.3	46.2
Pennsylvania	(1)	(1)	(1)	(1)	6.9	53.0
Tennessee	.55	.31	.26	.05	15.7	46.8
Virginia	1.85	.55	.47	.08	14.0	25.6
Washington	1.50	1.43	1.20	.23	15.8	80.1
West Virginia	42.03	16.41	15.36	1.05	6.4	36.5
Undistributed [2]	28.56	15.83	14.74	1.09	5.5	22.0
Total at mines only	115.40	59.03	53.37	5.66	9.6	46.3
Consumers plants		8.13	7.71	.42	5.2	
Grand total		67.16	61.08	6.08	9.0	

[1] Included in "Undistributed."
[2] Includes Arkansas, Colorado, Maryland, Montana, New Mexico, and Pennsylvania. Percentage figures represent results for Arkansas, Maryland, Montana, and New Mexico only.

The raw materials at some of the coal preparation plants include refuse banks and culm piles. This is particularly true in the anthracite region where these piles are being worked over. In 1938 the amount of anthracite coal reclaimed amounted to 2,340,444 net tons, a portion of which was passed through the breakers.

Another source of production of anthracite coal is through dredges working along the streams to reclaim fines discharged by mining operation nearer the headwaters. The extent of various operations in Pennsylvania is shown in table Cw–7 together with the total production.

TABLE Cw–7.—*Anthracite coal production in Pennsylvania*

[Millions of tons]

	1934	1935	1936	1937	1938
State (excluding Sullivan County):					
Breakers [1]	55.14	49.27	51.46	48.98	43.60
Washeries	1.19	2.11	2.35	2.02	1.88
Dredges	.65	.59	.55	.76	.57
Sullivan County: Breakers	.19	.19	.22	.09	.05
Total	57.17	52.16	54.58	51.85	46.10

[1] Breaker product includes a certain amount of culm bank coal; 617,000 tons in 1935; 987,000 tons in 1936; and 561,960 tons in 1938.

WASTE DISCHARGES

Many sources of waste discharge are prevalent at a preparation plant, although some occur primarily in a dry or semi-dry state. Plants operating with wet processes probably contribute more than all the others put together, especially if no treatment is practiced. Operations with closed systems require cleaning occasionally, or closing down for repairs, in which case tanks or basins may be discharged to surface drainage. Failure of dikes or terraces may also contribute considerably to the discharges, while spills and drainage of equipment and transporting vehicles should not be overlooked.

TABLE Cw–8.—*Analyses of Coal Washery Influents and Effluents* [1]

Source results in parts per million	Acid $CaCO_3$ Phen.	Alk. $CaCO_3$ M. O.	Hardness $CaCO_3$	Total iron as Fe	Solids: Total	Solids: Suspended	Biochemical oxygen demand 5-day 20° C.
Plant A:							
Raw water	12	----------	128	2	----------	----------	3.7
Discharge	----------	86	1,002	850	----------	----------	----------
Plant B:							
Raw water	8	280	155	----------	728	----------	1.9
Discharge	8	228	150	----------	108,000	101,000	----------
Plant C:							
Raw water	20	92	385	----------	1,290	----------	1.6
Discharge	8	108	380	----------	49,900	41,600	20
Plant D: Discharge	8	144	90	----------	208,000	201,000	10

[1] Records of coal washery effluents are few. Table 8 shows the results of analyses on grab samples which indicate the conditions at 4 plants.

Dry materials, from dusting and screening operations, go in with the general refuse discharge to fills and dumps. These deposits are rarely of sufficient distance from the streams to prevent stream wash, and although the material packs readily, erosion from rains and freshets may be the source of large quantities of slurry.

Some plants, after partial treatment of wastes, discharge them to old mine workings through drill holes or back of refuse piles, both of which may be of unsound judgment in that the drainage of wet material will produce acid loadings on the receiving stream. Table Cw–9 shows by analyses the effect of waste piles on streams.

As the quantity of impurities present may vary in coal from different locations and preparation plants are so widely different in their operations, it is impossible to draw up any comparative scale based on discharge of solids.

TABLE Cw-9.—*Stream Analyses in the Vicinity of Gob Piles*

Determination	Gob pile A		Gob pile B		Gob pile C	
	Above	Below	Above	Below	Above	Below
Run-off in million gallons per day	0.072	0.086	0.720	0.864	0.058	0.058
pH	3.3	3.1	2.8	3.0	5.3	3.2
Total acidity to phenolphthalein parts per million	80	240	880	1,350	8	120
Acidity cold to methyl red parts per million	50	180	420	680	4	90
Total acid in pounds per day	48	173	5,280	9,720	4	96

TABLE Cw-10.—*Estimated quantities of refuse from selected small wet coal-cleaning plants*

Raw coal (tons daily)	Refuse (tons daily)	Type system
250	2	Closed.
200	10	Partial overflow to stream.
1,150	90	Do.

WATER SUPPLY

Water supply for use at washing plants is generally obtained from wells, streams, or mines. Wells rarely supply the entire consumption as the cost of drilling would prohibit such expenditure when other means are available. Streams are the common source, although treatment may be necessary, especially if the water is highly acid. Mine water is often used and in slope mining regions may furnish complete requirements under gravity head. Mine water, however, if acid, usually requires treatment.

Water is used in a preparation plant mainly for supplying a medium whereby impurities can be separated from the coal and to act as a vehicle for the removal of these impurities.

Quantities of water consumed vary considerably in the various plants, and largely depend upon the type of operations carried out. In closed systems the make-up water depends mostly upon the quantity of moisture carried out with the coals and refuse, and therefore has a direct bearing on the quality of the coal and the amount of equipment employed. The quantity of water circulated per ton of washed product is fairly constant for a wide range of capacity using the same type of equipment, but varies considerably with different methods. The amount of impurities removed will also affect the quantity of recirculated water. It is stated that the skillful use of the principle of withdrawing a portion of the dirty water from appropriate places in the flow system to be clarified or discharged to sludge ponds can largely overcome differences in water circulation quantities.

It is therefore apparent that the quantity of water, make-up and recirculated, depends upon the efficiency and types of methods employed in washing, analysis of raw product, and clarification of washing wastes.

Water consumed, if taken from stream or mine, may be highly acid and require treatment in separate equipment before entering the preparation plant or may be neutralized by adding an agent such as hydrated lime to the settling basins. Some coals increase the acidity of water consumed and may make it necessary to treat the water after contact with the product.

POLLUTION EFFECTS

From available information which is somewhat limited, it is doubtful if waste slimes discharged from coal-washing activities has any serious bacteriological effect on the streams. The biochemical oxygen demand of effluents is very low and compares favorably to a healthy stream.

General opinion is that coal washery wastes are acid. This appears not to be true, however, and several reasons may be noted in explanation. Many mines "rock dust" the workings with pulverized limestone to reduce explosion hazards and a sufficient amount of this dust is transported with the coal to the washeries to neutralize the acids formed. It is also believed that without "rock dusting" an ample supply of natural limestone is mixed with the coal in mining to produce alkaline waste effluents.

Solids discharged to surface waters direct from washeries and indirectly from sludge and refuse dumps may cause considerable nuisance to recreation beaches, impair the quality of sand and gravel deposits, and reduce the tangible value of inundated lands. Numerous references indicate that black carbon fines may be carried many miles downstream to be deposited along the bank or spread over the bottom. On certain streams in the anthracite fields of Pennsylvania, the river beds are sufficiently covered to make recovery of coal fines profitable. Sand and gravel companies are reported seriously objecting to carbon particles in their product, which are a result of waste discharges; also nuisance complaints by boating interests in lower Schuylkill Basin are recorded. From tests available on fertility of soils, no objection can be raised due to inundated farm lands with this waste. However, because of the compactibility of these solids, soils may become difficult to work and their appearance may be repulsive. Another objection to the depositing of these solids in streams is possible damage to fish food.

Treatment of Wastes

Many types of machines and equipment are used to clarify coal washery wastes. These may employ settling, filtering and coagulation. Practically all plants practice recovery of fines, especially if wet processing is used. This consists of settling the water in tanks, and using flight conveyors to draw out the settlings. The slurry, or overflow from the tanks, may be: (1) discharged to the stream, (2) continued through further settling and treatment with eventual recirculation, or (3) recirculated with dilution water added for make-up.

Additional treatment following recovery of fines may consist of further settling in ponds, Imhoff cones, or rotary thickeners, with drying of sludge in centrifugal forced heat equipment. Effluents from ponds may be discharged to surface drainage or pumped for recirculation.

The use of coagulants such as swollen potato starch and lime are reported to improve the performance of filters and thickeners.

Wastes with quiescent settlement from 30 minutes to one hour are reported to show a supernatant liquid which is free of visible matter but is slightly darkened due to suspended matter. Final settling basins require cleaning from time to time to retain effective depth and detention time. This sludge is generally deposited behind dumps or along the terraces of the ponds.

Present information indicates that the best treatment of coal washery wastes involves chemical precipitation or settling aided by the use of coagulants. In plants with closed systems the treatment is sufficient and the nuisances and complaints have been eliminated.

Wastes from gob or refuse piles may be eliminated or considerably reduced by several remedial measures. Selection of the proper location should be the first consideration in depositing this waste, where drainage can be minimized and controlled. Old dumps can be isolated from stream courses by rerouting through new channels or by tunnelling the piles and installing conduits. Seepage and drainage from dumps can be restricted, by ditching and retention in ponds, well-terraced.

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(17) Minerals Year Book, 1939.

Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–12

INDUSTRIAL WASTES

River Mileage Index No. *S 85.5*

Type of Plant: *Coal Washery.* State: *Kentucky.*
Name of Plant: *Black Diamond Coals, Inc.*
Municipality: *Black Diamond.* Main Watershed: *Salt River.*
County: *Coal.* Subwatershed ______.
Address: *R. D. #2.*
Source of Information: *U. A. Jones, Tipple Foreman.*
Plant Operation:
Average; 35 hrs. per week, 130 days per yr.—12 plant employees.
Maximum; 55 hrs. per week, 50 days per yr.—12 plant employees.
Seasonal Variation: *Depends upon mining operation and sales.*

(Survey report continued on next page)

Survey by *J. D. Reed.* Date: *Nov. 15, 1940*

Sewered Population Equivalent Computation:
Factors used:
B. O. D. ______. Suspended solids ______.
Sewered population equivalent* based on B. O. D. ______.
Sewered population equivalent* based on suspended solids ______.
Remarks:
This plant has a closed water system, no wastes reaching the stream.
Computation by: *M. L. Wood.* Date *11/25/40.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

*Rounded to nearest 100.

(*Typical inspection report continuation sheet*)

Black Diamond Coals, Inc. S 85.5
R. D. #2,
Black Diamond, Ky.

Water Supply: Private well for drinking. Mine supply for plant make-up. Average 35,000 G. P. D., Maximum 50,000 G. P. D. Mine water slightly acid at times and lime used.
Raw Coal Entering Plant Daily: 250 Tons at full capacity. Coal crushed to 6 inches, 6″ x 1″ to cars, 1″ to 0 washed, ¼″ x 0 finer sewered.
Sulphur content: Raw coal 1.2%, Refuse 2.1%.
Coal Loaded Daily: 235 Tons (Approx.)
Washing and Preparation Processes: Rheylareur trough washers, hand picking and magnetic separation belt.
Wastes are treated and water is reused.

Clean-outs monthly are pumped to a pond. Pickings and refuse, 12.5 tons daily, go to a gob pile about 200 feet from stream.

Treatment of wastes consists of a settling tank, 60′ x 15′ x 8′, and primary and secondary settling cones.

pH tests made daily average 7.5.

Outlet: There is no apparent outlet and the stream gives no evidence of the discharge of washery wastes.
Sanitary Sewage is discharged to a septic tank and thence to Salt River. No complaints.

COAL WASHERY WASTES (Not an Actual Plant)

Plant: Black Diamond Coals, Inc. State: Kentucky Ref.No. S 85.5

City: Black Diamond County: Coal Main Watershed: Salt River

Address: R D # 2 Sub-watershed:

Informant: U. A. Jones Title: Tipple Foreman

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	35	130	12
Maximum	55	50	12

Seasonal variations: Depends upon mining operation and sales

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	Well	Negligible		None
Industrial	Mine	35,000	50,000	None
Cooling	None			

Make-up water only

RAW COAL ENTERING PLANT DAILY:- 250 T. (Full capacity)

Fractions: Crushed 6" x 0" Washed 1" x 0"

Recovered 1/4" x 0 Recrushed 4" x 1 1/2"

Chemicals

SULPHUR CONTENT:- Raw Coal 1.2 % Refuse 2.1 %

COAL LOADED OR STORED DAILY:- 235 T. (approx.)

WASHING AND PREPARATION PROCESSES:- Rheolaveur trough washers, hand picking magnetic separation belt

WASTES:- Quantity: Closed system How estimated: Make-up by pump rating

Recovery Eff.: to treatment Dryer Eff.: to treatment

Clean-outs:- once monthly (pumped to pond with seepage to ground)

Disposal other than water carried:- pickings & refuse 12.5 T. daily piled 200' ± from stream

Spills or Other Wastes

Treatment: Settling tank 60' x 15' x 8' – Settling cones (primary & secondary)

Analyses:- Number 26 Date Nov. 1940 By whom Company

Appearance: pH 7.5 (tests daily)

OUTLET:- Where to: None

Description:	Size and Shape	Material	Location	Elevation
1.				
2.				

Gaging possibilities: None

Conditions below outlet: Color: Stream appearance good

Turbidity Deposits

SANITARY SEWAGE:- Disposal: Septic tank Persons tributary: 12

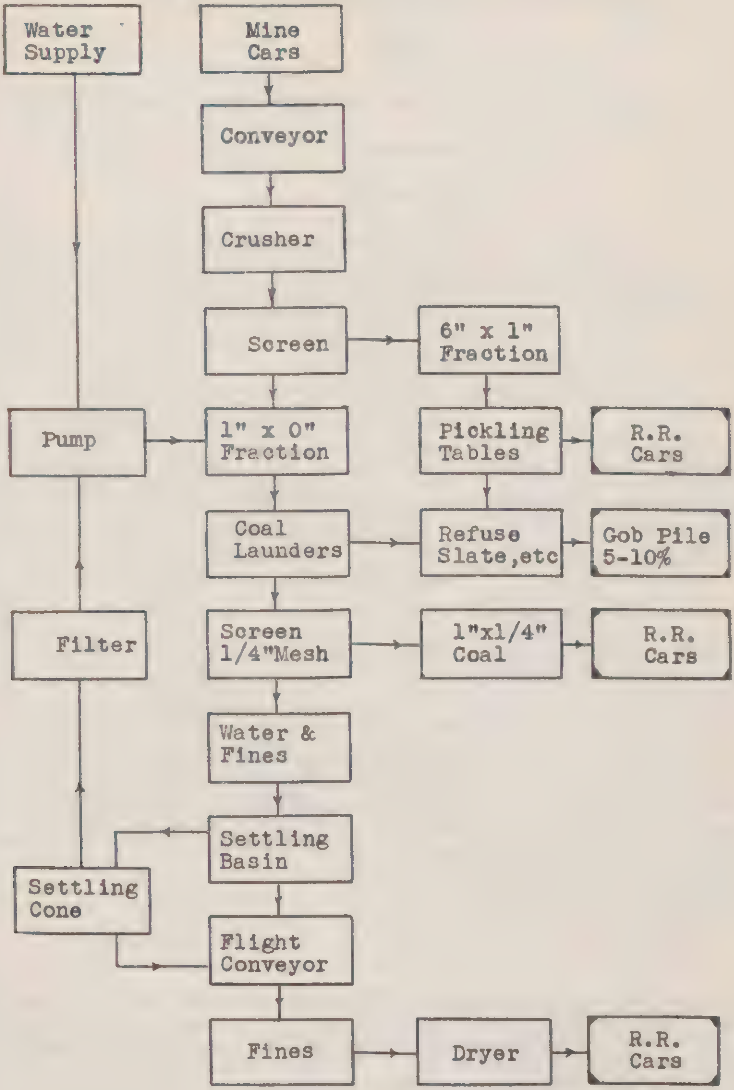
REMARKS: Mine water slightly acid at times and lime used

Survey by: J.D. Reed Date: 11 – 15 – 40

FLOW DIAGRAM

COAL WASHERY

Closed Water Recovery System



Ohio River Pollution Survey
U. S. Public Health Service
1942

APPENDIX IV OF SUPPLEMENT D

COKE

An Industrial Waste Guide to the Coke Industry

CONTENTS

LIST OF TABLES

Abstract

The byproduct coke process consists of the destructive distillation of coal to produce gas, coke, ammonia liquor, and coal tar. From these, particularly the coal tar, a great many further products are derived, although only the four primary products are customarily produced at the byproduct coke plant.

Byproduct coke plant wastes are notable chiefly because of their phenol content which causes tastes and odors in public water supplies. However, oxygen requirements of the wastes, although less often mentioned, are of consequence.

Table Ck–1 gives quantities and rounded figures for strength and sewered population equivalents of the wastes broken down as much as is possible with present information.

TABLE CK-1.—*Sources and rounded figures for quantities and strengths of byproduct coke plant wastes*

Source of waste	Biochemical oxygen demand, 5-day, 20° C., parts per million	Phenol (parts per million)	Quantity of waste, gallon	Sewered population equivalent, biochemical oxygen demand [1]
			Per ton of coal carbonized	
Ammonia still	4,000	2,000	22	5
Final cooler	650	100	315	4
Benzol carrying	220	10	15	1
Cooling water			3,200	
Other				5
Total	85	[2] 20	3,600	15

[1] Based on 0.168 pound, biochemical oxygen demand (5-day, 20° C.) per capita.
[2] Computed.

Pollution reduction measures at byproduct coke plants as now practiced are largely in the nature of changes within the plant. The nearest approach to actual treatment is in the reduction of phenol discharges and even here most methods used are of an industrial recovery rather than a treatment type.

Disposal of materials other than to the sewer include evaporation of a portion of the quench water, dumping of agitator acid wastes on slag piles, and burning of the pure still residue.

Oxygen requirements of byproduct coke plant wastes have received little attention. These requirements can be reduced by recirculation of final cooler water. A gravity oil separator on the light oil and crude still waste lines is desirable and refining or pure still residue should not be discharged to the sewer.

The removal of phenols from coke wastes has received considerable attention following public water supply taste and odor troubles. Efficient phenol recovery units are now in successful operation.

DESCRIPTION OF PROCESS

The process described in this guide is believed to be typical of a byproduct coke plant using the direct system of ammonia recovery. There are two general methods of ammonia recovery known as the direct system and the indirect system, respectively. To avoid confusion and also because the direct system is the more common, it alone will be described.

Coal of a suitable quality, when heated in the absence of air (oxygen), can be destructively distilled to produce gas, coke, ammonia liquor, and tar.

This destructive distillation is carried out in narrow horizontal retorts placed side by side. They are usually set in groups of from 6 to 9 in what is known as a bench. The group of benches, varying with the capacity of the plant, is known as the stack. The retorts are charged through openings in the roof, and discharged by a ram from one end.

The items of equipment following the stack and the purposes for which they are used in connection with the four products are briefly described as follows:

GAS

(1) Ascension pipe: A device connecting the byproduct coke oven retorts with the collecting main. Gas receives some preliminary cooling from a spray of ammonia liquor at this point.

(2) Collecting main or hydraulic main: Large diameter pipes used to conduct gas, ammonia liquor, and tar from the retorts to the byproduct recovery apparatus. Recirculating ammonia liquor further cools the gas during its flow through these mains.

(3) Primary coolers: The retort gas is again further cooled by a powerful spray of ammonia liquor, the liquor, in turn, being cooled by the plant cooling water in indirect cooling coils.

(4) Decanter: A device to separate gas, ammonia liquor, and tar by taking advantage of their difference in density. A part of the ammonia liquor thus

separated is returned, after cooling, to the primary coolers to reduce the temperature of the hot retort gas. The balance or excess ammonia liquor is piped to the ammonia liquor storage tank for ultimate recovery of ammonia.

(5) Exhauster: To create suction on the ovens and mains and to boost the gas above atmospheric pressure.

(6) Tar extractor: After the major portion of the tar has been separated from the ammonia liquor in the decanter, the small amount of tar remaining in the gas is precipitated out by an electrical or mechanical process.

(7) Saturators: The partially cooled gas, now freed of ammonia liquor and tar but still containing free ammonia, is passed through sulfuric acid, which reacts with the ammonia to form ammonium sulfate which is removed and sold.

(8) Final coolers: A high velocity water spray, coming in direct contact with the gas, further cools it and causes separation of crude naphthalene.

(9) Benzol absorbers: Counter-current scrubbing of the gas with "wash oil" results in the absorption of benzol in the "wash oil" and its effective removal from the gas.

(*a*) Stripping still: By distillation the crude benzol is separated from the "wash oil." After cooling the stripped "wash oil" is returned to the benzol absorbers to pick up another load of benzol.

(*b*) Agitator: To remove resins and other impurities the benzol is agitated with sulfuric acid. The acid is removed by drawing off from the bottom of the agitator. In order to neutralize any excess acid a second wash is carried out with caustic soda. A final wash with water is common practice.

(*c*) Pure still: A final distillation is made in this apparatus for the fractionization of benzene, toluene, and xylene. Some plants do not separate the benzol into the above fractions but sell a single combined distillate known as "motor spirits."

(10) Gas storage: Gas is conducted to a storage holder. Where the gas is to be used for domestic purposes or in certain chemical plants removal of minor impurities is necessary.

COKE

(1) Quench tower: The incandescent coke, when rammed out of the retorts, is collected in a special car and transported to a building in which the hot coke is deluged with water.

(2) Sorting and grading: After cooling, the coke is sorted and graded for size and then goes to storage for eventual sale or plant use.

AMMONIA LIQUOR

(1) Ammonia liquor storage: The excess ammonia liquor, separated from the tar and gas in the decanter, is piped to a container for storage.

(2) Ammonia still: This still is composed of two parts, the free leg and the fixed leg.

(*a*) Free leg: By distillation with steam free ammonia is driven off in this section of the still.

(*b*) Fixed leg: By the addition of calcium hydroxide (from quick lime) the chemically combined fixed ammonia is converted to free ammonia.

The latter is driven off by steam distillation. The free leg and fixed leg are not physically separate units but are integral parts of the ammonia still. Phenol recovery methods operate on the weak ammonia liquor before it enters the ammonia still as in the benzol extraction process or withdraw the ammonia liquor from the free leg, dephenolize, and return the treated ammonia liquor to the fixed leg as in the Koppers vapor recirculation process. These phenol recovery processes are discussed more fully under phenol removal and recovery.

(3) Ammonia saturators: The free ammonia, liberated in the ammonia still, is absorbed in sulfuric acid to produce ammonium sulfate.

TAR

Byproduct tar is recovered from the decanter and the tar extractor. The accumulated tar is stored in tanks. It is the practice in some plants to add to the tar thus collected the crude naphthalene which is set free in the final cooler. The usual procedure among byproduct coke manufacturers is to sell the crude tar to coal-tar refiners. The latter recover phenol, cresylic acid, carbazole, phenanthrene, anthracene, naphthalene, pyridine, cumenes, and acenaphthene, which are important starting materials for synthetic organic compounds.

Raw Materials and Products

RAW MATERIALS

Table Ck-2 shows the principal raw materials required by a byproduct coke plant and the approximate quantities of each as pounds per ton of coal carbonized per day. The character of the coal, the type of retort, and the time and temperature of carbonization, each affect the quantity of benzol and ammonia liquor which, in turn, will govern the amount of chemicals needed for their treatment.

Table Ck-2.—*Raw materials used in byproduct coke plants*

[Pounds per ton of coal]

	Sulfuric acid 66° B.	Caustic soda [1] 95 percent	Lime [2]
Maximum	28.	0.52	1.8
Minimum	18.	0.23	1.0
Average	26.	0.39	1.3

[1] Includes only that used in agitator for benzol washing.
[2] Includes only that used in converting fixed ammonia to free.

PRODUCTS

Coke is considered here to be the principal product as such is the case when the byproduct coke plant is associated with a steel mill. However, gas may be the product and coke a byproduct, as when gas is manufactured for domestic use. The type of coal selected, the carbonization rate (time and temperature), and the retort design will each influence the relative amount of product and byproduct. The type of coal selected or the blend of coals used and the regulation of carbonization conditions will be adjusted in any one plant to favor the product from which the greatest profit may be obtained. Table Ck-3 and table Ck-4 show the quantity of product and byproducts usually derived per ton of coal carbonized per day.

Table Ck-3.—*Products and byproducts from byproduct coke plants*

Product or byproduct	Unit	Units per net ton of coal charged	
		Maximum	Minimum
Coke	Pound	1525.	1300.
Coke breeze	Pound	100.	68.
Tar	Gallon	12.	5.
Ammonium sulfate	Pound	26.	17.
Gas	Cubic foot	11300.	10300.
Crude phenol	Pound	2.	0.1
Benzene	Gallon	2.	1.1
Toluene	Gallon	0.5	0.2
Xylene	Gallon	0.2	0.1
Naphthalene	Pound	1.2	0.5

Table Ck-4.—*Average yield of coke and byproducts in byproduct ovens in the United States, 1920–38*

[Data from Bureau of Mines]

Product	Unit	Yield of coke and byproducts units per net ton of coal charged				
		1920	1925	1930	1936	1938
Coke	Pound	1395.	1398.	1380.	1409.	1399.
Tar	Gallon	8.2	8.4	9.20	8.86	9.27
Ammonium sulfate or equivalent	Pound	21.4	22.4	23.47	[1] 22.14	[1] 23.36
Light oil	Gallon	[1] 2.7	[1] 2.9	[1] 3.06	[1] 2.91	[1] 2.99
Gas	1,000 cubic feet	10.8	11.2	11.05	11.06	11.04

[1] Average for plants recovering this commodity.

Coke: The amount of coke produced is roughly 70 percent of the coal carbonized.

Coke breeze: The dust produced during the coking operation is known as breeze. The breeze is commonly recovered from the quench water but may be discharged to the sewer in the excess quench water.

Tar: The amount of tar produced is greatly influenced by the coal selected and the time and temperature of the coking operation.

Ammonium sulfate is recovered from both the gas and the ammonia liquor. Roughly 67 percent of the total ammonium sulfate is recovered from the gas and the balance from the ammonia liquor.

Gas: Like the tar, the quantity of gas varies widely with manufacturing conditions.

Crude phenol:[1] The figures shown in table Ck–3 represent the actual crude phenol recovered, as recently reported by three plants, and not the theoretical amount as estimated from analysis of ammonia liquor and ammonia still waste. Phenol is recovered under most circumstances to eliminate taste and odor troubles in downstream water supplies, rather than on account of its value as a byproduct.

Benzene, toluene, and xylene: The benzol may be fractionated into benzene, toluene, and xylene or a single fraction, known as motor spirits, may be run off and sold.

Naphthalene is usually sold to coal tar refiners as crude naphthalene for subsequent purification or it may be added to the tar. In general, it is true that a coal containing a high quantity of volatile matter will yield an increased amount of gas, tar, and benzol, whereas a coal of high fixed carbon content will favor the production of increased quantities of coke. Most ovens use a blend of high and low volatile coals. High oven temperatures reduce the yield of tar and heavy light oils, but increase the benzol yield.

EMPLOYEES

The ratio of employees to coal carbonized as reported by four plants varied considerably. This variation is open to several explanations.

(1) The degree of purification of the gas will depend upon the purpose for which the gas will be used. Domestic gas requiring a high degree of purification will naturally require more labor in its preparation.

(2) A byproduct coke plant, which is a subordinate part of another industry (steel mill or chemical plant), would be expected to have less employees per ton of coal coked than a plant which was entirely independent. As an example, the independent plant might require the services of eight mechanics, whereas the coke plant, associated with a larger industry, would be maintained by the mechanical force of the parent organization.

(3) In general, the ratio of employees to coal carbonized per day will probably, other factors being equal, vary inversely as the size of the plant.

A ratio of 8 persons per 100 tons of coal coked per day is probably a satisfactory figure for a byproduct coke plant producing coke for a steel mill, using the gas for industrial heating, and recovering ammonium sulfate and phenols.

TABLE CK–5.—*Ratio of employees to raw materials in byproduct coke plants*

	Employees[1]		Employees[1]
Plant A[2]	20	Plant C	6
Plant B	9	Plant D	7

[1] Per 100 tons coal carbonized per day.
[2] Produced gas for domestic use.

[1] Includes phenols, cresols, and similar substances.

Sources and Quantity of Waste

SUMMARY

Table Ck–6 summarizes the various wastes to be expected from a byproduct coke plant and shows the approximate quantity of each to be expected.

Table Ck–6.—*Quantities of wastes from various sources in byproduct coke plants*

Waste	Gallons per ton of coal carbonized	Waste	Gallons per ton of coal carbonized
Water carrying waste products:		Cooling water	3,200
Ammonia still	22	Disposal other than to sewer:	
Final cooler	315	Quench water to atmosphere	125
Benzol carrying	15	Spent sulfuric acid	(1)
Spent caustic	(1)	Pure still residue	0.6

1 Small.

AMMONIA STILL

Table Ck–7 shows the volume of ammonia-still waste per ton of coal carbonized The figures are based on a 6 months period in 1939. Plant C did not recover ammonium salts and distillation was carried out for the purpose of removing phenol only. Therefore, the volume of ammonia still waste is somewhat less than normal.

Table Ck–7.—*Volume of ammonia still waste from byproduct coke plants*

	Ammonia-still waste—gallons per ton of coal carbonized			
	Plant A	Plant B	Plant C	Plant D
Maximum	22	26	18	37
Minimum	16	17	15	32
Average	19	21	16	36

Table Ck–8 shows to what extent the ammonia-still waste may be expected to vary with the quantity of ammonia liquor. In general, a volume of 22 gallons of ammonia-still waste per ton of coal carbonized per day may be expected.

Table Ck–8.—*Relation of quantities of ammonia liquor to ammonia-still waste in byproduct coke plants*

	Gallons per ton of coal carbonized		Ratio of ammonia-still waste to ammonia liquor
	Ammonia liquor	Ammonia-still waste	
Plant A	16	19	1.2
Plant B	17	21	1.2
Plant C	15	16	1.1
Plant D	24	36	1.5

FINAL COOLER

The quantity of water used in the final cooler will vary with the temperature of the cooling water and the volume of gas cooled. Many plants recirculate the final cooler water, thus eliminating this source of pollution. Table Ck–9 gives some idea of the volume of the final cooler waste water in gallons per ton of coal carbonized. An average figure of 315 gallons may be used for rough calculations.

TABLE Ck-9.—*Volume of final cooler water from byproduct coke plants*

	Final cooler water—gallons per ton of coal carbonized			
	Plant A	Plant B	Plant C	Plant F
Maximum			298	376
Minimum			169	284
Average	150	542	210	356

BENZOL CARRYING

Direct steam distillation in the stripping, and pure stills of wash oil, and light oil results in a condensate from these units which carry oily substances generally referred to as benzol. The volume of this benzol-carrying waste discharged in gallons per ton of coal carbonized is shown in table Ck-10. The quantity of this waste will depend upon the quantity of benzol in the gas which, in turn, is largely determined by the nature of the coal and the carbonization rate. While the figures presented show considerable variation, a volume of benzol-carrying waste of 15 gallons per ton of coal carbonized should serve as a representative value for the majority of plants.

TABLE Ck-10.—*Volume of benzol-carrying water from byproduct coke plants*

	Benzol-carrying waste—gallons per ton of coal carbonized				
	Plant A	Plant C	Plant E	Plant F	Plant G
Maximum				14	
Minimum				10	
Average	40	14	5	13	12

COOLING WATER

Very limited data indicates the amount of cooling water to be as shown in table Ck-11. Since the effectiveness of cooling will depend upon the temperature of the cooling water, the volume of cooling water will decrease as the temperature of the cooling water decreases. It is believed that the value of 3,200 gallons is ample and most nearly represents the quantity of water used for cooling in the average coke plant.

TABLE Ck-11.—*Volume of cooling water from by product coke plants*

	Cooling water—gallons per ton of coal carbonized		
	Plant C	Plant E	Plant F
Average	3,200	3,200	1,936

LIGHT OIL—CAUSTIC WASH

A small amount of spent caustic soda solution is discharged to the sewer during the purification of the light oil in the agitator Recent data indicates that about 0.4 pound of 95 percent caustic soda is used in the agitator per ton of coal carbonized per day.

CHARACTER OF WASTES

SUMMARY

Important byproduct coke-plant wastes come from the ammonia still, the final cooler, and from the stripping and pure stills. The ammonia-still wastes contain phenol and are often treated for the removal or recovery of this substance. Oxygen requirements are chiefly from the ammonia-still and final-cooler wastes.

AMMONIA STILL

The results of analyses made on the ammonia-still waste of three plants during 1936 and 1937 are shown in table Ck–12. The figures are based on averages of daily composite samples taken over a period of 11 to 15 days. The waste was not treated for phenol recovery or removal.

TABLE Ck–12.—*Analyses of ammonia-still wastes from byproduct coke plants*

Determination	Results in parts per million					
	Plant E	Plant F		Plant G		Average
	1936	1936	1937	1936	1937	
Biochemical oxygen demand 5-day 20° C	2, 440	5, 240	4, 290	4, 200	3, 700	3, 974
Suspended solids:						
Total	131	626	258	122	647	356
Volatile	84	252	139	65	225	153
Nitrogen:						
Organic and NH_3	107	194	274	344	485	281
Organic	79	169	183	260	242	187
Phenol	1, 360	2, 320	2, 790	1, 640	2, 170	2, 057
Cyanide				110		110
pH	8. 9					8. 9

FINAL COOLER

Table Ck–13 was prepared from analyses made in 1936 and 1937 of the final cooler effluent of one plant. As in the case of the ammonia still waste, table Ck–12, these analyses are based on 24-hour composites over a period of 12 days. As already mentioned, recirculation of final cooler water is carried out in many plants. An analysis of the water being recirculated at one plant gave the results shown in table Ck–14.

TABLE Ck–13.—*Analyses of final cooler water from one byproduct coke plant (plant F)*

Determination	Results in parts per million		
	1936	1937	Average
Biochemical oxygen demand, 5-day 20° C	115	322	218
Total suspended solids	[1]	12	
Nitrogen, organic and NH_3	14	13	14
Phenol	113	98	105

[1] Less than intake.

TABLE Ck–14.—*Analysis of final cooler water from closed recirculating system of a byproduct coke plant*

[Average at two 24-hour composite samples]

Determination	Results in parts per million	Determination	Results in parts per million
Biochemical oxygen demand, 5-day 20° C	3, 165	Nitrogen:	
Total solids:		Organic plus ammonia	227
Total	690	Ammonia	56
Volatile	368	Phenol	1, 645
Suspended solids:		KCN	145
Total	51	Sulfates	130
Volatile	23		

BENZOL CARRYING

Waste from the various distillation processes in the purification of benzol when analyzed showed results as in table Ck–15. The figures shown in this table were based on 24-hour composites averaged over a period of 11 to 15 days.

TABLE CK–15.—*Analyses of benzol purification wastes from byproduct coke plants*

Determination	Results in parts per million				
	Plant E	Plant F		Plant G	Average
	1936	1936	1937	1936	
Biochemical oxygen demand, 5-day 20° C	1,093	87	908	500	647
Suspended solids:					
Total	27	95	180	196	125
Volatile	27	60	120	183	97
Nitrogen:					
Organic and NH_3	27	28	23	4	20
Organic	13	14	11	2	10
Phenol	6	6	264	12	72
pH	6.6				6.6

COMBINED WASTES

Table Ck–16 was prepared from limited data on the combined byproduct coke plant waste effluent, including cooling water, after correcting for the raw water analysis.

SEWERED POPULATION EQUIVALENT

Based on biochemical oxygen demand.—From table Ck–17, and using the total volume of waste from each of these three plants, the sewered population equivalent based on the biochemical oxygen demand has been calculated per ton of coal carbonized per day. It is believed that a population equivalent of 15 persons per ton of coal carbonized, based on the biochemical oxygen demand, is a reasonable estimate until more complete information is available. Estimated sewered population equivalents of the several waste producing units are shown in table Ck–18.

TABLE CK–16.—*Analyses of combined waste from byproduct coke plants based on limited data*

	Nature of samples	Phenol, parts per million	Total suspended solids, parts per million	Biochemical oxygen demand, 5-day, 20° C. parts per million
Plant C	Single catch sample	[1] 6.4	(2)	96
Plant E	Average of 11 daily 24-hour composites		[3] 89	93
Plant F	Maximum for single 24-hour composite		(2)	125
	Minimum for single 24-hour composite		(2)	53
	Average of 11 daily 24-hour composites		(2)	76

[1] Phenol was reduced at this plant by distillation and coke quenching.
[2] Less than intake.
[3] Included coke breeze.

TABLE CK–17.—*Sewered population equivalent of combined wastes from byproduct coke plants based in biochemical oxygen demand*

	Nature of sample	Sewered population equivalent per ton [1] of coal carbonized per day
Plant A	Single catch sample	17
Plant B	Average of 11 daily 24-hour composites	10
	Maximum for single 24-hour composite	15
	Minimum for single 24-hour composite	6
Plant C	Average of 11 daily 24-hour composites	15

[1] Based on 0.168-pound 5-day, 20° C. biochemical oxygen demand per capita per day.

TABLE CK–18.—*Estimated sewered population equivalents of waste from various sources in byproduct coke plants*

Source of waste	Sewered population equivalent biochemical oxygen demand [1] per ton of coal carbonized per day
Ammonia still waste	5
Final cooler waste	4
Benzol carrying waste	1
All other by difference	5

[1] Based on 0.168-pound 5-day, 20° C. biochemical oxygen demand per capita per day.

Based on suspended solids.—Insufficient information is available at this time with respect to the population equivalent based on suspended solids, to assign a value of reasonable worth. One plant showed less suspended solids in the effluent than in the raw water at the intake. This is no doubt partly due to condensate making up a considerable share of the total waste water. A second plant in which coke breeze was wasted to the sewer had a population equivalent of 10 persons per ton of coal carbonized.

POLLUTION EFFECTS

OXYGEN

Oxygen depletion by byproduct coke plant wastes, while important, has not caused widespread complaint probably because of the fact that most plants are located on relatively large streams.

PURE STILL RESIDUE

Resinous deposits are reported in the vicinity of the outfall from one plant that appeared to be discharging pure still residue to the stream.

PHENOLS

As is well know, phenols in even small concentrations are detrimental to public water supplies. In higher concentrations phenols are detrimental to fish life. Data on these effects are summarized as follows:

(1) It has been reported that phenol in quantities of 0.002 to 0.005 parts per million in the presence of chlorine will produce medicinal chlorophenol tastes and odors in water.

(2) A concentration of 0.1 part per million of phenol alone imparts to water the characteristic taste and odor of phenol.

(3) Ellis states that in fish phenol produces paralysis of the neuromuscular mechanism and hemolyzes the blood. Table 19 shows the results of studies of goldfish in phenol contaminated water.

TABLE CK-19.—*Survival time of goldfish in phenol contaminated water*

Phenol concentration	Survival time of goldfish
1,000 parts per million	15 to 30 minutes.
100 parts per million	60 to 72 hours.
10 parts per million	72 hours to over 4 days.[1]
1 part per million	Over 4 days.[1]

[1] No apparent injury to fish.

Experiments conducted by Dr. Carl Hubbs, institute for fisheries research, University of Michigan showed (table Ck-20) that byproduct coke plant ammonia still waste, when sufficiently diluted to give values of ammonia and phenol as shown in columns two and three, respectively, would produce death in resistant types of fish (*Hyborhynchus notatus*) in the time noted in columns three and four. Furthermore, Shelford, Wells, Forbes and Richardson and others found that fish react positively toward phenol—that is, instead of avoiding this pollution, they swim toward higher concentrations..

TABLE CK-20.—*Survival time of resistant fish (Hyborhynchus notatus) in phenol-ammonia contaminated water*

	Ammonia, parts per million	Phenol, parts per million	Time before death			
			Aerated		Nonaerated	
			Hours	Minutes	Hours	Minutes
Sample No. 2	10.0	4.00	5	02	1	57
	8.0	3.2	100	00	64	15
Sample No. 4	10.0	5.43	4	05	5	35
	8.0	4.43	10	00	10	00
	6.0	3.25	23	35	100	00

REMEDIAL MEASURES

SUMMARY

Byproduct coke plant pollution remedial activities have concentrated on the phenol problem. Recovery and removal units with efficiencies of from 90 to 95 percent are in operation. Oxygen requirements, which have received less attention, can be reduced by about 30 percent by recirculation and reuse of offending waters.

RECOVERY PRACTICES

The recovery of byproducts may be carried out for either of two reasons: (a) For the profit to be had from their sale; or (b) to eliminate nuisance or other objectionable conditions caused by their discharge into streams.

Ammonium sulphate, crude tar, napthalene, coke breeze, gas, benzene, toluene, and xylene are recovered because of their economic value. One plant producing ammonia compounds synthetically, found it uneconomical to recover the ammonium salts from their byproduct coke plant. Information has been received that at least one byproduct coke plant is commercially recovering ammonium chloride from the ammonia still waste.

Phenol, while of value, is recovered or removed primarily to prevent chlorophenol taste and odor from developing in downstream water supplies. Under favorable conditions the value of the crude phenol about covers the operating cost of recovery. Phenol recovery and removal methods are discussed in detail later in this guide.

DISPOSAL OTHER THAN TO SEWER

Quench water.—During the quenching operation water is lost to the atmosphere as steam. Data obtained from four plants indicate that the volume lost in this manner is roughly 125 gallons per ton of coal carbonized per day.

Agitator acid waste.—Sulfuric acid (66° Be.) is commonly used to wash the light oil to remove resins, etc. The amount of acid used in this manner is about 1.6 pounds per ton of coal coked per day and is disposed of by dumping on slag piles.

Pure still residue.—A residue of about 0.6 gallon per ton of coal carbonized per day remains in the bottom of the pure still after the distillation process. This residue is usually burned.

MISCELLANEOUS POLLUTION REDUCTION PRACTICES

Quench water.—The water used to quench the incandescent coke is partially lost to the atmosphere as steam, while the excess water always present may be disposed of in three ways:

(1) Run to waste with the resulting loss of coke breeze (coke dust) and eventual deposition of the breeze in the receiving body of water.

(2) Collection of the excess quench water in a sedimentation basin; recovery of the coke breeze; disposal to sewer of the comparatively clear supernatant liquid.

(3) If the clear liquor from the second method as described above is reused for coke quenching, after adding what fresh water is necessary, a completely enclosed system is the result, with no waste being discharged to the sewer. This system is commercial practice in many plants.

A marked reduction in suspended solids can be expected as the result of changing from method No. 1 to method No. 3. The cost of additional equipment to reuse water from the sedimentation basins for quenching of hot coke is approximately $3,000 per 1,000 tons of coal carbonized per day and the operating cost will be roughly $3 per 1,000 tons of coal carbonized per day.

Ammonia still waste liquor.—With the exception of phenol and ammonium chloride recovery, the information available at present indicates that no other pollution reduction practices are followed commercially on the amomnia still waste.

Final cooler water.—A large amount of water (approximately 315 gallons per ton of coal coked per day) is used in the final coolers. This water comes in direct contact with the byproduct coke gas and thus may carry considerable contamination. Many plants allow the effluent from the final cooler to run directly to the sewer, others recirculate the water through cooling towers. A portion of the recirculated water may be used for coke quenching, making up the loss of final cooler water with fresh water, or the recirculating water may be discharged periodically to streams during high water conditions and the system refilled with fresh water.

Analysis shows the phenol content of the final cooler effluent to be about 100 parts per million and the sewered population equivalent per ton of coal carbonized per day to be about 4 persons, based on the biochemical oxygen demand. Thus, by converting the common direct discharge final cooler to a recirculating system, a material reduction in the population equivalent and in waste phenol content may be secured.

The initial cost of a closed indirect final cooler recirculating system is about $25,000 per 1,000 tons of coal carbonized per day and operating costs are approximately $6.50 per 1,000 tons of coal carbonized per day.

The question of atmospheric pollution by hydrogen sulfide vapors is involved in the installation of atmospheric type coolers. A closed indirect cooler does not discharge hydrogen sulfide vapors. However, such a cooler requires removal of naphthalene to reduce stoppages. The atmospheric type cooler is, in general, greater in initial cost.

Benzol still waste.—Condensate from the various benzol stills is contaminated with wash oil and benzol or light oil. This oily material may be present as oil in water emulsions or as free surface oil. Gravity separators should be, and usually are, employed to remove the free oil. That oil in the form of emulsions is largely wasted to the sewer. Gravity separators can be installed at a cost of approximately $3,000 per 1,000 tons of coal carbonized per day.

Agitator acid waste.—This waste is disposed of by dumping on slag piles in the great majority of byproduct coke plants. Methods have been devised whereby this waste is treated with steam to recover the sulfuric acid. The dilute acid thus recovered is suitable for use in the ammonia saturators.

Agitator alkali waste.—The alkali waste from the agitator is customarily run to the sewer.

Pure still residue.—This viscous resinous material remaining in the bottom of the pure still after the xylene, benzene, and toluene have been distilled off, is usually disposed of by burning or dumping on slag piles. One plant investigated appeared to be discharging this material to a stream, resulting in resinous deposits in the vicinity of the outfall.

Phenol Removal and Recovery

Methods of treatment may be divided roughly into two classifications:

Removal of phenols and their conversion into nontaste and odor producing compounds which may safely be wasted.

Recovery of phenols as crude phenol or sodium phenolate having some commercial value.

REMOVAL OF PHENOLS

Biological treatment.—Phenols may be oxidized in natural waters, biological filters, or by the activated sludge process to nontaste and odor producing compounds. However, the phenol must not be present in too large quantities otherwise a toxic effect will be produced on the organism causing the oxidation.

Eldridge states that work by Bach indicated that the phenol content for natural purification must be not over 25 parts per million. Streeter concludes, from information obtained from operators of municipal water purification plants located along the Ohio River, that phenols are reduced by natural purification, this phenomenon being, in general, made of action similar to that commonly associated with the self-purification of streams.

Eldridge found, in a survey of the literature, a wide difference of opinion as to the amount of ammonia still waste which may be safely mixed with sewage to be treated in an Imhoff tank. A ratio of 1 to 2,000 is suggested by Shindman, the gas research committee a 1 to 200, and Sperr states that 1 part of still waste to 10 parts of sewage may be handled. The phenol is apparently not destroyed by the anaerobic action of the Imhoff tank.

Oxidation process, such as trickling filters and activated sludge, will destroy phenols. Mohlman found that 25 to 30 parts per million of phenol may be treated safely on a sand filter and 30 to 40 parts per million by the activated sludge process.

In general, it may be stated that biological treatment of phenolic waste has been found uneconomical for individual byproduct coke plants on account of the large treatment area required and the high dilution necessary for satisfactory operation of the biological processes. However, byproduct coke plant waste may be run to a municipal sewer and satisfactorily treated, provided there is sufficient dilution of domestic sewage, by activated sludge or on trickling filters. This method provides an economical solution for disposal of byproduct coke plant waste at some plants.

Coke quenching.—One of the first commercial methods of treating ammonia still waste was the use of this waste for quenching the incandescent coke. This method has two distinct advantages: (1) Complete evaporation of the ammonia still waste, (2) utilization of heat which would otherwise be wasted. On the other hand, there are a number of serious objections to this process; i. e., extensive corrosion of plant equipment by the calcium chloride contained in the still waste; poor appearance and odor of the coke which is not conducive to its sale for domestic use. A flow diagram marked "Phenol removal system A" is appended which shows the operation of coke quenching with ammonia still waste in a completely enclosed system.

Distillate coke quenching.—In order to take advantage of the simplicity and cheapness of the coke quenching method of phenol removal, and yet eliminate the high corrosion losses, the following method of treatment was devised by one company.

The ammonia liquor was steam distilled in a regeneration column. The vapor issuing from the still is condensed and run to the quenching pit for use in quenching the coke. It is this distillate which contains the phenols and certain other volatile compounds. The corrosive chlorides remain in the still and are continuously run to waste.

Since the coke is not intended for domestic consumption, difficulty from unpleasant odors, due to the absorbed phenol from the quench water, is not experienced. This plant does not recover ammonium salts.

Table Ck–21 shows the efficiency of phenol removal. The figures shown in the table are averages of weekly composite samples which were analyzed once a week,

then averaged for the month. A brief flow sheet is attached to this guide which shows the various operations and their sequence in the distillate coke quenching operation. The diagram is marked "Phenol removal system B."

TABLE CK–21.—*Phenol reduction in ammonia liquor by distillate coke quenching in a byproduct coke plant*

[Average phenol content in parts per million]

Sources of wastes	June 1939	July 1939	August 1939	September 1939	Average
Ammonia liquor	1,146.0	905.0	903.0	1,255.0	1,052.0
Ammonia still waste	59.0	31.0	40.0	54.0	46.0
Percent removed	94.1	96.0	95.4	95.1	95.1

RECOVERY OF PHENOLS

The Koppers vapor recirculation process.—This system may be described briefly as follows:

Ammonia liquor from the bottom of the free ammonia still is sprayed into the top tower section. It flows down over the wooden-hurdle packing, where it is contacted with a large volume of steam passing counter current to the liquor. Due to the vapor pressure of the phenol, it passes into the steam. The dephenolized liquor passes, by gravity to the fixed leg of the still. The blower draws the steam from the top of the tower and discharges it into the lower, or caustic section. Here it is scrubbed with a solution of sodium hydroxide, which is added in intermittent shots through the sprays of the lower section. The steam, thus stripped of its phenol, reenters the top section, completing the cycle.

The caustic soda, in absorbing the phenols, is converted to sodium phenolate. This spent caustic solution flows to the phenolate storage tank. From here it is pumped in batches to the springing tank, where flue gas, rich in carbon dioxide, is bubbled through the solution. The phenols are released from combination with the soda and separated by gravity from the aqueous solution of sodium carbonate formed in the reaction. The sodium phenolate may also be sold directly or "sprung by" any of the other usual agents, such as stack gas, sodium bicarbonate, or sulfuric acid.

In table Ck–22 is shown the efficiency of this process as operated in two plants. The figures are averages of daily tests in the case of plant D and in the case of plant B are averages of about six determinations made during the month.

TABLE CK–22.—*Phenol removal efficiency of vapor recirculation process in byproduct coke plants*

[Average phenol content in parts per million]

Source of waste	April 1939	May 1939	June 1939	July 1939	August 1939	Average
Plant B:						
Ammonia liquor	3,027.0	4,784.0	4,708.0	2,860.0	2,774.0	3,631.0
Ammonia still waste	525.0	718.0	691.0	520.0	503.0	591.0
Percent removed	78.3	82.0	81.8	79.0	77.0	79.6
	June 1939	July 1939	August 1939	September 1939	October 1939	Average
Plant D:						
Ammonia liquor	2,706.0	2,791.0	2,385.0	2,276.0	2,581.0	2,548.0
Ammonia still waste	150.0	171.0	166.0	166.0	205.0	172.0
Percent removed	92.3	91.4	90.2	88.8	88.5	90.2

The cost of constructing a unit to recover phenol by the vapor-recirculation dephenolization process will naturally vary with local conditions, with the amount of duplicate equipment required for uninterrupted operation, and the size of the plant as measured by the number of tons of coal carbonized per day. Table Ck–23, however, shows the approximate cost for various size installations.

TABLE CK-23.—*Approximate installation cost, vapor recirculation process for phenol recovery in byproduct coke plants*

	Cost of dephenolization plant
Tons of coal carbonized per day:	
1,000 and under	$35,000
2,000	60,000
4,000	101,000
8,000	150,000
16,000	206,000

The flow sheet marked "Phenol recovery by Koppers dephenolization process" appended to this guide will aid in an understanding of the process.

Benzol extraction process.—In this process the ammonia liquor is treated for removal of the phenols before the liquor enters the ammonia still, rather than removing the liquor from the free leg of the ammonia still for treatment as in the vapor recirculation process. A flow sheet of this process is attached to this guide. Reference to this diagram will aid in understanding the following description of the benzol extraction process.

Weak ammonia liquor is pumped to the top of No. 1 absorbing tower. The liquor then passes down through beds of egg-sized coke, then out the bottom and up to the top of No. 2 absorber. The liquor next passes down through No. 2 absorber. From No. 2 absorber it flows out the bottom and into the dephenolated liquor storage tank.

Against this flow of ammonia liquor is passed motor benzol. The benzol is pumped from the circulating tank to the bottom of No. 2 absorber. It passes into the absorber directly underneath a perforated plate, and, due to the difference in the specific gravity of benzol and ammonia liquor, it passes up through the plate, through the beds of coke, and collects at the top of the absorber. It is then pumped to the bottom of No. 1 absorber, through which it passes in the same manner. During its passage through the slowly moving ammonia liquor, the benzol thoroughly scrubs the liquor and absorbs from it the dissolved phenol.

The phenol laden benzol flows from the top of No. 1 absorber into the bottom of one of the caustic washers after which it passes up through the caustic solution and collects in the space above the caustic level. It is then pumped into the bottom of a second caustic washer. From the top of the second washer it passes to the benzol tank to be recirculated through the system again. While the benzol containing phenol passes through the caustic washers, the caustic soda unites with the phenol to form sodium phenolate.

Liberation of the phenol may be brought about by adding concentrated sulfuric acid to the sodium phenolate to form phenol and sodium sulfate. The latter is wasted to the sewer. The phenol thus produced has approximately the following analysis:

	Percent
Phenol (volume)	54
Cresols	23
Water	16
Tarry matter	7

It may be used without refining in the manufacture of sheep and cattle dips and other crude disinfectants. After refining, it is a source of pure phenol and cresols used in the manufacture of bakelite, antisepetics, dyes, and so forth. Table Ck-24 shows the efficiency of this process as operated in one plant.

TABLE CK-24.—*Phenol removal efficiency of benzol extraction process in byproduct coke plants*

[Average phenol content in parts per million]

Phenol in	May 1939	June 1939	July 1939	August 1939	September 1939	Average
Ammonia liquor	4,950.0	6,200.0	5,612.0	5,958.0	5,665.0	5,677.0
Ammonia still waste	125.0	140.0	68.0	50.0	52.0	87.0
Percent removed	97.1	97.0	98.5	97.8	99.0	97.7

The present tendency in byproduct coke plants recovering phenol by either the Koppers vapor recirculation process or by the benzol extraction process is to sell the sodium phenolate directly to coal tar refiners rather than springing the crude phenol at the byproduct plant.

Absorption by activated carbon.—The absorption by activated carbon of phenols has been considered but not applied commercially in this country. Removal of the phenol, after absorption by the activated carbon, has been accomplished with varied success by—

(1) Distillation with super-heated steam.
(2) Extraction with benzene.
(3) Extraction with caustic soda.

The process of extraction with benzene has been in commercial use in Germany. Eldridge has attempted the removal of the phenol from the activated carbon by the use of caustic soda solution on a laboratory scale.

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(34) Removal and Recovery of Phenols from Ammonia Sulphate Still Effluents by D. W. Parkes, J. Soc., Chem. Ind., 46: 186, 1927.
(35) Elimination of Phenols from Effluents of Coking Plants by W. Fitz, Asphalt, u, Terr. 30: 522, 1930.
(36) Removal of Phenols from Crude Ammonia by Activated Carbon by F. Sierp, Gas u. Wasserfach 76: 105, 1933.

Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–3

INDUSTRIAL WASTES (*Not an actual plant*)

River Mileage Index No. *K 62.3*

Type of Plant: *Byproduct coke.* State: *W. Va.*
Name of Plant: *Consolidated Coke Co.*
Municipality: *Charleston.* Main Watershed: *Kanawha.*
County: *Kanawha.* Subwatershed -------
Address: *P. O. Box 13, Charleston, W. Va.*
Source of Information: *Mr. John Doe, Superintendent.*
Plant Operation: *168 hrs. p. wk.—365 da. p. yr.*
Employees:
Av. office 16, plant 330.
Max. office 20, plant 340.
Seaslnal Variation: *None.*

(Survey report continued on next page)

Survey by *Howard Blank.* Date: *March 6, 1940*

Sewered Population Equivalent Computation:
Factors used *per ton of coal carbonized per day:*
B. O. D.: *15.* Suspended solids ------
Sewered population equivalent* based on B. O. D.: *18,000.*
Sewered population equivalent* based on suspended solids ------
Remarks:
Quench is completely enclosed system.
Final cooler water not recirculated.
Koppers Vapor recirculation dephenolization system.
Computation by *M. L. Wood.* Date: *4-15-40.* Cincinnati Office

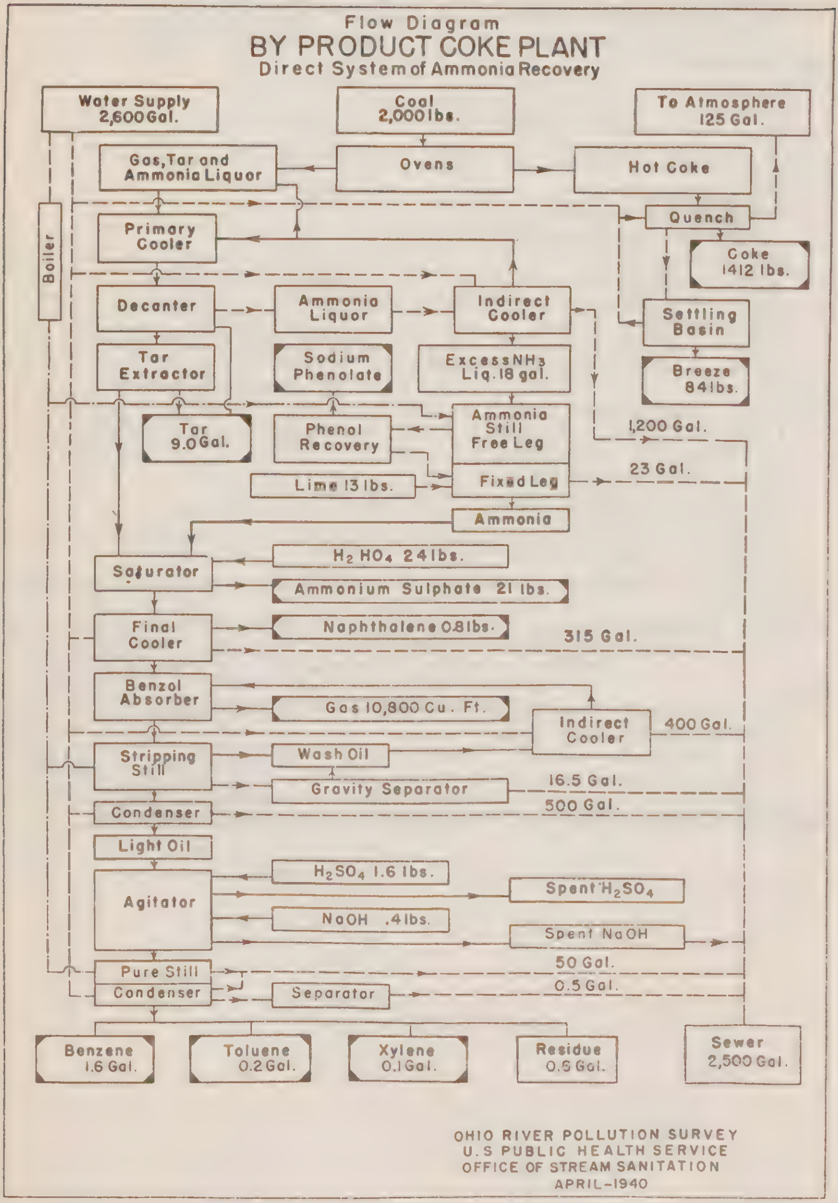
*Rounded to nearest 100.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

(*Typical inspection report continuation sheet*)

Consolidated Coke Co., I–3
Charleston, W. Va. K 62.3

Water Supply:
Drinking—from city mains—Av. 34,600. Max. 36,000 g. p. d.
Industrial—Kanawha River—Av. 500,000. Max. 700,000 g. p. d.
Cooling—Kanawha River—Av. 2.5. Max. 3.0 Mil. g. p. d.
Raw Materials:
Coal—1,200 T. p. d.
Sulphuric Acid (26° Be)—15.6 T. p. d.
Caustic Soda (95%)—468 lb. p. d.
Lime—1,560 lb. p. d.
Products:
Coke—840 T. p. d.
Crude Phenol—1,000 lb. p. d.
Total, ammonium sulphate—12 T. p .d.
Tar—9,600 g. p. d.
Xylene—120 g. p.d.
Benzene—2,400 g. p. d.
Toluene—240 g. p. d.
Naphthalene is separated in final cooler and added to the crude tar. Crude tar is sold as such and not refined.
Wastes:
Total (from metered supply less loss in quenching)—2.8 mil. g. p. d.
Final Cooler (not recirculated)—378,000 g. p. d.
Ammonia Still Waste—26,000 g. p. d.
Benzol Carrying—18,000 g. p. d.
Quench water lost to atmos.—150,000 g. p. d.
Cooling—2.46 mil. g. p. d.
Spent sulphuric acid and residue from pure still are dumped on slag pile or burned.
Phenol is recovered as crude phenol by the Koppers Vapor recirculation process.
Analysis: Analyses show an average ammonia liquor phenol content of 3021 p. p. m. and the ammonia still waste contained 112 p. p. m. A recovery efficiency of 96.5%. Analyses are made daily by plant lab.
Outlets:
18″ circular tile at east end of Co. property, carrying cooling water, storm water, and sanitary waste.
2 6″ outlets carrying final cooler water, ammonia still waste, and benzol carrying waste, at rear of quench tower and 50′ west of pump house. All may be measured by weirs in channel between outlet and river.
Remarks: Company does not contemplate any immediate expansion.


Flow Diagram
BY PRODUCT COKE PLANT
Direct System of Ammonia Recovery
Water Supply 2,600 Gal.
Coal 2,000 lbs.
To Atmosphere 125 Gal.
Gas, Tar and Ammonia Liquor
Ovens
Hot Coke
Quench
Boiler
Primary Cooler
Coke 1412 lbs.
Decanter
Ammonia Liquor
Indirect Cooler
Settling Basin
Tar Extractor
Sodium Phenolate
Excess NH3 Liq. 18 gal.
Breeze 84 lbs.
Tar 9.0 Gal.
Phenol Recovery
Ammonia Still Free Leg
1,200 Gal.
Lime 13 lbs.
Fixed Leg
23 Gal.
Ammonia
Saturator
H2 HO4 24 lbs.
Ammonium Sulphate 21 lbs.
Final Cooler
Naphthalene 0.8 lbs.
315 Gal.
Benzol Absorber
Gas 10,800 Cu. Ft.
Indirect Cooler
400 Gal.
Stripping Still
Wash Oil
Gravity Separator
16.5 Gal.
Condenser
500 Gal.
Light Oil
H2SO4 1.6 lbs.
Agitator
Spent H2SO4
NaOH .4 lbs.
Spent NaOH
Pure Still
50 Gal.
Condenser
Separator
0.5 Gal.
Benzene 1.6 Gal.
Toluene 0.2 Gal.
Xylene 0.1 Gal.
Residue 0.5 Gal.
Sewer 2,500 Gal.
OHIO RIVER POLLUTION SURVEY
U.S PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL-1940

BY-PRODUCT COKE PLANT WASTES (Not an actual plant)

Plant Consolidated Coke Co. State W. Va. Ref. No. K 623

City Charleston County Kanawha Main Watershed Kanawha

Address P.O. Box 13, Charleston, W. Va. Sub-watershed ———

Informant Mr. John Doe Title Super Principal Product Coke

Plant Operation:

	Hours per Week	Days per Year	Plant Employees
Average	168	365	330
Maximum	168	365	340

Seasonal variation None

WATER SUPPLY:

	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City Supply	34,600	36,000	Coag.-Sed.-Filt.-Chlor.
Industrial	Kanawha R.	500,000	700,000	None
Cooling	Kanawha R.	2.5 Mil.	3.0 Mil.	None

COAL PROCESSED DAILY 1,200 Tons

Chemicals: Sulphuric Acid 15.6 T.-26°Be Sodium Hydroxide 468 lb. Lime 1,560 lb.

PRODUCTS:- Daily Average: Coke 840 Tons Phenol 1,000 lb.

Ammonium Sulfate 12 Tons Tar 9,600 gal. Xylene 120 gal. Benzene 2,400 gal.

Toluene 240 gal. Tar (Shipped as such) 100 % (Processed) 0

WASTES:- Quantity 2.8 Mil. gal. p.d. How estimated metered Supply quench

Character: F. Cooler 378,000 gal. p.d. Quenching 150,000 gal. p.d.

Ammonia still waste 26,000 gal. p.d. Cooling and condensing 2.46 Mil. g.p.d.

Carrying benzol 18,000 gal. p.d. Recirculating None

Disposal other than water carried Spent H_2SO_4 & still residue to Slag pile

Possible spills no recent history Type phenol recovery Kappers Vapor Circulat'n

EFFLUENT ANALYSES: Number daily Date — By whom Plant Lab.

P.P.M. Phenol: Ammonia Liquor 3021

Ammonia still wastes 112 Per cent phenol recovered 96.5

OUTLET: Where to Kanawha River

Description:

	Size and Shape	Material	Location	Elevation
1.	18" Cir.	Tile	East end	Co. Property line
2.	6" Cir.	Cast iron	Rear of	quench tower
3.	6" Cir.	Tile	50' West of	pump house

Gaging possibilities Good - weir in channel from outlets to River

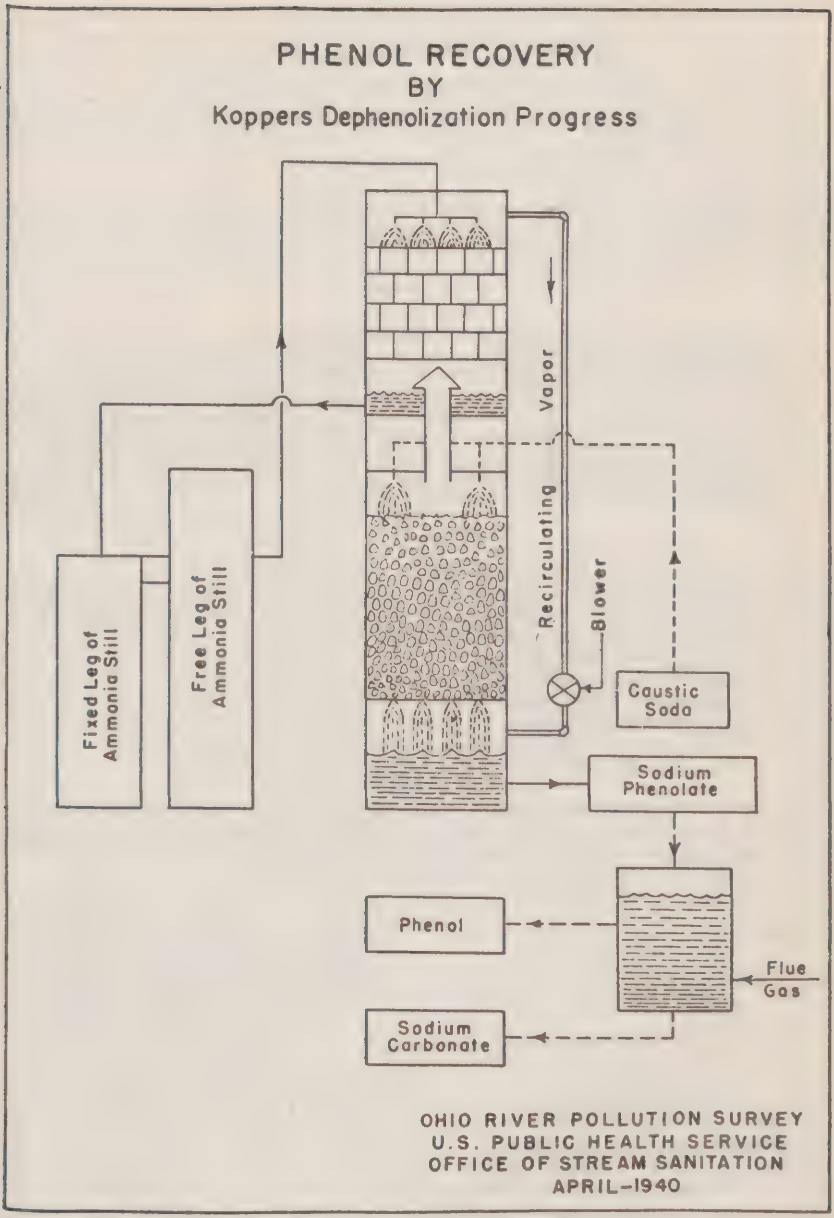
Conditions below outlet: Color Some oils

Turbidity Slight Deposits none

SANITARY SEWAGE: Disposal run to Kanawha Persons tributary 346

REMARKS Quench is completely enclosed Sys. Final cooler water not recirculated. No increase in capacity contemplated.

Survey by Howard Blank Date 3-6-1940


PHENOL RECOVERY
BY
Koppers Dephenolization Progress
Vapor
Recirculating
Blower
Caustic Soda
Sodium Phenolate
Fixed Leg of Ammonia Still
Free Leg of Ammonia Still
Phenol
Sodium Carbonate
Flue Gas
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
APRIL-1940

APPENDIX V OF SUPPLEMENT D

COTTON

An Industrial Waste Guide to the Cotton Industry

CONTENTS

LIST OF TABLES

Abstract

Cotton is transformed from the staple to the finished cloth in two general procedures; first, the fabrication of the fiber to fabric, and, second, the processing of the cloth. It is from the processing of the cloth that the major portion of the liquid waste emanates. Considerable waste may originate from the processing of raw stock and treatment of warp.

Textile wastes are noted for pollutional and chemical strength, toxicity, and tinctorial properties. They are common pollutional offenders and have proven difficult to purify by ordinary sewage-treatment facilities. The most polluting wastes are obtained from the deterging and dyeing operations. These wastes are large in volume, strong chemically, and highly polluting.

Table Ct-1.—*Cotton textile wastes: Summary of waste discharge and sewered population equivalents per 1,000 pounds of goods processed per day, with typical analytical results for various cotton wastes*

Industry	Wastes, gallons per 1,000 pounds of goods	Typical biochemical oxygen demand 5-day 20° C. parts per million	Sewered population equivalent per 1,000 pounds of goods processed per day (biochemical oxygen demand)
Cotton:			
Sizing	60	820	2
Desizing	1,100	1,750	96
Kiering	1,700	1,240	108
Bleaching	1,200	300	17
Scouring	3,400	72	12
Mercerizing	30,000	55	83
Dyeing:			
Direct	6,400	220	71
Basic	18,000	100	100
Vat	19,000	140	130
Sulfur	5,400	1,300	360
Developed	14,400	170	120
Naphthol	4,800	250	59
Aniline black	15,600	55	41

Typical formulas for each process have been presented, followed by the analyses of the waste produced. Pollutional equivalents shown on table Ct–1 may be applied to the wastes, affording a means of comparison with domestic sewage, and a method of estimating the pollutional quantity of similar waste from other mills. Composite wastes from a number of cotton mills have been presented. Typical variations occur although a sewered population equivalent of 20 per 1,000 gallons of waste appears to be a representative average.

Recovery and reuse of the waste liquors or other pollution reduction measures have lagged although latent possibilities exist. Chemical treatment and equalization of flow, either alone or followed by treatment in a municipal sewage-treatment plant, offer the best possibilities for correcting this type of pollution.

Description of Processes

The description of the processing of cotton fiber to the finished product has been subdivided into three general classifications: "Fabrication," tracing the raw cotton to thread, yarn, or cloth; "deterging," describing the methods by which the material is cleaned, bleached, and finished or prepared for dyeing; and "dyeing," describing some of the coloring practices.

FABRICATION

Fabrication comprises processes of carding, spinning, spooling and warping, slashing and drawing, weaving and knitting,

Carding department.—Raw cotton as received by the mill has been ginned and compressed into bales of approximately 500 pounds. The bales are opened and the cotton mechanically mixed, and made fluffy. Partial cleaning occurs during the process. Cotton may be dyed in this form called raw-stock dyeing, in preparation for weaving into cloth such as denim (overall material). The raw-stock dyeing process will be described later.

The next operations consist of picking, carding, combing, drawing, and roving. Picking continues the cleaning process, putting the cotton into laps of uniform density. The loosely matted layers or laps resemble absorbent cotton. Carding changes the cotton lap into a loose untwisted rope or sliver. Combing is performed to produce fine yarns and continues the work of the carding machine by cleaning and combing out the short fibers and tangles. Combing places the fibers parallel to each other. Drawing allows 4 to 6 strands of sliver to be combined and drawn or drafted into a single sliver of the same diameter or weight as those entering the machine. Roving is a term denoting the cotton sliver after it has been drafted and reduced in size, slightly twisted and wound on a double bobbin. The machines are usually called roving frames. Roving may be dyed in this form similar to raw-stock dyeing.

Spinning department.—The roving delivered to the spinning frame is drafted or drawn to the required size and twisted to give maximum strength. The twist is imparted to the yarn by the spinning frame. Yarn designed for filling (woof, weft, picks, or crosswise threads) is ready for the weaving department when spun on bobbins suitable for use in the loom. Warp threads (ends) undergo further treatment. Material for use in blue denim and similar cloth may be yarn dyed as described under indigo dyeing. Thread and cord is prepared by spinning into the desired line or thread.

Spooling and warping department.—Spooling consists of winding the yarn from a large number of small bobbins onto a large spool that feeds the warper. Warping is the operation of winding from 300 to 400 warp ends on a large section beam to be used for weaving. Beamed warp is processed and dyed similar to chain warp.

Slashing and drawing departments.—Slashing is the process of treating the yarn with starch and softeners that aid in weaving and protect the fiber from damage. The materials applied to the yarn are called sizing. Drawing-in or tying-in is the method of separating the ends of the warp and drawing them through the drop wires, harness, and reed according to weaving practice. Machines are used to tie-in the warp from the new section beam to the yarn remaining from the old section beam, eliminating the tedious procedure of drawing-in each individual thread.

Weaving department.—The warp, beam, after tying-in, is placed on the loom. The loom mechanism, by means of the harness, raises part of the warp threads and lowers the rest, making a V-shaped opening through which the shuttle with the filling or weft thread passes. The position of the warp threads are then reversed and the filling locked into the warp by a forward motion of the reed.

Knitting.—Knitting is the making of cloth with only one set of threads by catching one loop into another. The yarn may be carried crosswise to the fabric called weft knitting or lengthwise to the fabric called warp knitting. Weft knitting is used in the making of hosiery and underwear, the important fabrics of cotton knitting.

DETERGING

Cloth from the loom is in the gray or called gray goods. Gray goods is the untreated and unfinished cloth probably obtaining its name from the appearance of the material. Many mills produce only gray goods to be finished elsewhere. Such mills generally have negligible amounts of industrial wastes.

Preparing the cloth for market involves many processes such as desizing, scouring, or kiering, bleaching, etc., before the goods can be dyed and/or finished. These are the cleansing or deterging operations.

First, the loose fibers are singed and then the sizing that was applied to the yarn is removed. Previous to dyeing, the natural waxy coating is removed from the fiber, allowing increased absorption of dye from the coloring solutions. Should bleaching be necessary, not only the waxy coating, but also impurities on the fiber must be removed. The material may be subjected to other miscellaneous processes prior to the dyeing or finishing procedures.

Singeing or gassing.—Singeing to burn off loose fibers is the first step in the finishing of the cotton cloth. The material is passed rapidly over an open gas flame and immediately dipped into a standing vat of water. Following this, the cotton may receive a gray wash which is a preliminary wet-out to remove external dirt, soften the fiber, and remove some sizing.

Desizing.—Desizing, the operation of removing the starch sizing that was applied to the yarn prior to weaving, may be accomplished by several methods. Sizing may be removed in the caustic kier boil, a method that is rapidly becoming popular, or in the kier boil after treatment with dilute sulfuric acid. This preliminary acid treatment, called the grey sour, softens the cloth and removes some of the starch. One of the most common methods of desizing is by steeping in malt or other enzyme bath for 30 minutes or more followed by an acid treatment or brown sour. Enzymatic bodies act readily upon the starch, converting it to soluble sugars and solubilize the pectin and waxy matter on the filter. Waste desizing liquors are highly polluting, although the volumes are small.

Scouring or kiering.—The presence of the waxy coating on the raw fiber causes it to be water repellent, hence difficult to impregnate with solutions. Therefore, cotton material must be scoured for dyeing or bleaching to remove the impurities and make the cloth absorbent for the operations that may follow. Scouring consists of boiling in a dilute solution of caustic soda, soda ash, soap, or other alkaline substances. Certain oils, such as turkey-red oil (sulfonated castor oil) also have the property of rapidly removing the cotton wax.

Scouring is usually accomplished by boiling under pressure in an iron kettle called a kier. Cotton is kiered from 8 to 12 hours at temperatures as high as 125° C. (257° F.) with pressures varying from 10 to 80 pounds. When kiering is not necessary, as in the case of deep colors, the cloth may be lightly scoured by a caustic solution in an open vat. This process is called wet-out. On the other hand, boiling is a very strong caustic solution in the open vat is called boil-out. After scouring, the cloth is thoroughly rinsed.

Modern practice tends to simplify procedure by kiering in a single pressure boil and eliminating the desizing and boil-out operations.

Kier liquor is the largest single waste from cotton mills and is the most harmful of all the wastes produced in the processing of cloth.

Bleaching or chemicking.—Cotton cloth is bleached extensively for white goods and as a preparation for level dyeing and the dyeing of delicate shades. The material is worked in a cold, dilute solution of chloride of lime (bleaching powder or chemic, $CaOCl_2$) or in a solution of sodium hypochlorite prepared by dissolving chlorine gas in a soda ash or caustic soda solution. The cloth is then squeezed by rollers and exposed to the air. Bleaching is brought about by action of the mild oxidizing agents such as hypochlorite. The bleaching agent breaks down slowly to chloride ion, liberating oxygen which reacts with the coloring matter, destroying the pigment.

Peroxides are also used to bleach cotton, especially when complete decolorization is not essential. This method is required for cotton-wool or cotton-silk mixtures. The reagents may be added directly to the kier bath or may be applied in a second kiering operation. The peroxide bleaching kier boil contains sulfuric acid, sodium peroxide, caustic soda, sodium silicate (a bleach assistant), and a soluble oil. The acid is completely neutralized, reacting with the peroxide and the waste is

alkaline. Acid is not required for commercial peroxide bleaching agents bought ready for use. The peroxide method of bleaching is said to be increasing in popularity. The waste is similar to that produced by ordinary kiering.

Souring or white sour is the treatment of the cloth with an antichlor such as sulfuric acid, sodium bisulfite or sodium hydrosulfite. Following bleaching, the cotton is first rinsed with water, then with the antichlor to remove decomposed material produced during bleaching, after which the cloth is thoroughly washed of salts and excess acid. The rinses after the white sour usually contain soap to soften the fiber and bluing should the cloth be bleach finished.

The bleach wastes, including spent bleach liquor, the white sour, and all rinses, are large in volume but seldom offer difficulties when combined with wastes from subsequent dyeing processes.

Finishing.—Finishing prepares the cloth for sale. A market bleach, as previously mentioned, must be tinted with bluing to intensify the bleach. In practically all instances, cotton cloth is finished by starching and then calendered (passed between steamed iron rolls) to increase the weight, to effect a good feel, and to improve the appearance by smoothing and polishing the surfaces. The waste produced in finishing is small in volume consisting of excess starch paste wasted at the termination of a run.

Miscellaneous processes.—Mercerizing is the process of subjecting cotton which is maintained under tension to a concentrated solution of caustic soda. The caustic soda reacts with the cotton, increasing the luster, sheen, strength, and affinity for dyes. The cotton is washed while under tension, then treated with dilute acid and washed again. The material is usually bleached after mercerizing. The waste from this process is mainly wash waters since the caustic is seldom dumped. The concentrated caustic bath is often reused elsewhere in the mill or recovered by evaporation or dialysis.

Plissé or crepe goods are materials produced to give a crinkle effect. This is achieved by printing strong caustic soda on the material either in stripes or squares. The cotton in contact with the caustic soda shrinks causing the characteristic ripping effect of plissé goods. The material is then washed, treated with dilute acid, and given a final rinse. The wastes are mainly wash waters containing the excess acid washed from the goods.

Sanforizing is the shrinking of cotton by forced contraction of a given length of material. The ribbon of cloth enters a machine consisting of a blanket rotating around a steam drum. The cloth is fed at a given rate, undergoes a steaming and, is removed from the machine at a reduced rate. Shrinkage is caused by steaming and the mechanical action of the blanket. There is no waste from the sanforizing process.

DYEING

Discussion of the dyeing process has been divided into two sections, one having to do with classification or description of the dyes used and the second having to do with the mechanism of dyeing.

Classification of dyes.—A comprehensive study of dyeing necessitates a classification of the dyestuffs based upon origin and chemical make-up or upon their application. The classification dependent upon origin and chemical make-up is of value. However, the type of waste may be more readily estimated from the classification according to application of the dyestuff.

In considering origin and chemical make-up, dyes may be classified as natural organic, mineral or inorganic, and manufactured organic. Natural organic dyes are of importance historically since they were the forerunners of the present dyeing industry. As the classification indicates, they are of natural organic origin found in vegetable and animal matter. These dyes are expensive although still used when bright, fast colors are required. Among the most common natural dyes are the following: Logwood, indigo (mainly replaced by the synthetic product), cutch, fustic, and cochineal. Mineral or inorganic dyes are of minor importance in the textile industry. Many are used in calico printing but only the following are of importance in the actual dyeing process: Prussian blue, chrome yellow, chrome green, and iron buff. Chromium salts are used as developers or developing aids and must not be confused with their use as dyes. Manufactured organic dyes include the entire group of so-called coal-tar dyes and form the most important group. Among these dyes may be listed: Magenta, benzopurpurine, acid violet, tetrazine, alizarines, anilines, naphthols, sulfurs, etc.

In considering the application of dyestuff, classifications include substantive or direct colors, basic dyes, vat dyes, sulfur dyes, developed dyes, naphthol colors, and aniline black. Printing, a separate method of applying dyestuff is also discussed.

Substantine or direct colors, as the name implies, have a direct affinity for cotton. These dyes are of neutral chemical nature and are soluble in water. Because of their great solubility, direct dyes are "salted out" with sodium chloride or sodium sulfate (Glauber's salt) and consequently sometimes are called salt colors. These dyes are also called dip dyes after the process. The waste from direct dyeing is, in most instances, the least polluting of all dye wastes although the solubility of direct dyes make it difficult to remove completely the color from the waste waters. Some direct colors, black in particular, are toxic and may interfere with biological processes.

Basic dyes are the salts of colored bases and are used primarily for their brilliancy. Since cotton does not possess acidic properties, combination with basic dye requires an acid mordant to be added to the fiber. A mordant is any substance which, combining with a dyestuff to form an insoluble compound or color lake, serves to produce a fixed color in a textile fiber. Tannic acid is readily abosrbed from solution by cotton and forms color lakes with basic dyes making it a suitable mordant in this connection. Following the boil-out, the cotton is saturated with tannic acid and to prevent the tannic acid from dissolving in the dye bath, an insoluble antimony tartrate is formed by treatment with tartar emetic. Acetic acid (leveling agent) is added with the dye to retard dyeing, producing a more even shade. An oil and soda ash finishing bath completes the treatment. Five wastes are usually produced during the basic dyeing process.

Vat dyes are so-called because they are applied in a dye bath or vat in which the dye is reduced to a soluble form. The dyes are insoluble in water but yield products on reduction by strong reducing agents, such as hydrosulfite, that are soluble in alkaline liquors. Vat dyes are characterized by great fastness to light, washing, acids, alkalines, and many to bleaching. The material to be dyed is immersed in a vat containing the dye, reducing agent, and alkali, and then oxidized either in the air or by soluble oxidizing compounds such as perborate of soda. The goods are soured to neutralize any remaining alkali. Each treatment is followed by a rinse. There are three distinct processing wastes: The dye liquor, the sour, and oxidizing solution, if used. Vat dye wastes are very alkaline and have a high chemical oxygen demand. These wastes are polluting in character.

Sulfur dyes belong to the general group of substantine dyes but, as the name implies, consist of sulfur compounds used with the addition of sodium sulfide. It is now known whether the sodium sulfide acts as a reducing agent, dye solvent or combines with the dyestuff to form a soluble compound. With sulfur black, sodium sulfide acts as a solvent. A neutral salt is added during the process to salt out more of the dye. Sulfur colors are remarkable for their fastness to washing and to acids in cross dyeing. Sulfur dyes are inexpensive and furnish deep heavy shades on cotton. The waste, consisting of the dye bath and rinses, is very alkaline, highly colored, extremely toxic, and is one of the most polluting dye wastes.

Developed dyes are colors converted or built up on the fiber. The original dye is a direct color and is applied in a fashion identical with direct color dyeing. The absorbed color is changed to a chemically unstable form by treatment with nitrous acid formed by sodium nitrite and either hydrochloric or sulfuric acid. The unstable azo body is next converted to a stable dyestuff by a developer, usually beta-naphthol. Developed colors are also called insoluble azo or diazotized and developed from the process, ice colors, since ice is used to obtain the cold temperature in making the dye and ingrain colors as the color is formed within the fiber. They are often classified with naphthol dyes as color made on the fiber. The developing process increases the fastness of the colors to washing and acids and also increases the intensity of the shade. Three main wastes are produced: The dye bath, the diazotizing bath, and the spent developing bath. Rinses follow each operation and usually a final salt rinse or soap treatment is given the dyed material.

Naphthol colors are produced by reversing the operations of developed dyeing and likewise are azo dyes built on the fiber. The cotton is first treated with a developer as beta-naphthol and then with a diazotized dye bath where the color is developed on the fiber. Naphthol dyes are fast to an extent surpassed only by vat dyes. Most are fast to soaping, washing, and light, while many resist bleaching by chlorine. Two major wastes are produced: The beta-naphthol and the diazotized dye liquors. A hot soap and soda bath is used for after treatment, brightening the colors and deepening the shades. Six wastes are usually produced including the rinses.

Aniline black is produced on the fiber by the oxidation of aniline hydrochloride. The color itself is an insoluble black pigment produced by the oxidation of aniline.

In practice, a mixture of aniline hydrochloride and an oxidizing agent such as potassium chlorate, potassium ferrocyanide, or copper sulfide is applied to the material or printed on the cloth. The subsequent drying and ageing processes produce conditions suitable for the oxidizing action that forms the black pigment. Aniline black is extensively used in calico printing and hosiery dyeing. It is exceptionally fast to light, bleaching, and washing. Aniline black, is rather expensive and the original bath is seldom dumped except at the end of long runs. The wastes are from the washing operations where the cloth passes through several vats; for example, one chrome bath, three plain rinses, and then three soap washes followed by two plain rinses.

Mechanism of dyeing.—Dyeing machines are of two general types, one allowing the material to pass through the dye vat and the other circulating the dye liquor through the material. Raw stock and roving commonly are dyed by circulating the dye liquor through the material. Sulfur dyes are used extensively. Yarn and chain warp most frequently are dyed in machines allowing the material to pass through the dye vats. An exception is the recent development of dyeing yarn on spools or cops by pumping the dye liquor through the material which is wound on perforated tubes.

Of special interest is the dyeing of chain warp with indigo using machines constructed solely for this purpose. The yarn first enters a box containing a hot, caustic solution and is then rinsed. Several vats of reduced indigo follow. After each indigo bath, the yarn is carried over many reels, exposing it to the air causing oxidation of the reduced compound. The colored yarn is washed and finally passed through a softening bath containing a mixture of oils and waxes. The dye vats are rarely dumped, the waste being produced by continuous overflow from the wash boxes.

Piece goods are dyed by passing the cloth through the dye bath. The continuous process is similar to the chain warp method and produces the same wastes; i. e., overflow from the wash boxes. For matching shades or for dyeing small quantities of goods, a machine called a jig is used. Briefly, a jig consists of a vat with rollers allowing cloth to pass from one roll down through the dye bath and up onto another roll. This procedure, called jigging, is repeated until the proper shade is obtained. Customarily, the bath is dumped after each roll of goods is dyed. Some mills using sulfur black dyes retain the vat, make up to strength, and reuse. The cloth is treated and rinsed in the same machine, using large volumes of water. The waste is voluminous and highly polluting, especially when sulfur dye predominates.

Hosiery is dyed in machines similar in appearance and operation to laundry washing machines. Capacities vary from 50 to 300 pounds. Customarily, hosiery is processed on a batch basis; all processes taking place in the same machine.

Stripping and redyeing or reworking is the process of redyeing material when the original color does not meet specifications. It is estimated that from 1 to 10 percent of the material in hosiery mills may be reworked. The color is removed or stripped by a bath consisting of soda ash and sodium hydrosulfite followed by a boil-off with soap. Other chemicals may be used in the stripping bath, dependent upon the type of dye. The material is rinsed and then redyed according to mill practice. A strong pollutional waste is discharged by this process.

Tinting is a light shade applied to cloth, yarn, or thread, primarily to distinguish types of material in the mill. This color must be readily removable or easily covered so the choice falls upon direct dyes. The amount of dye in the bath is small and the waste negligible.

Union dyeing is the dyeing of union material composed of cotton and wool or cotton and silk. The wastes will depend upon the type of dyeing. Direct dyes are used for union goods of cotton and wool.

Ingrain is a term usually applied to hosiery when the yarn is dyed prior to knitting.

Printing.—Textile printing differs from dyeing since the color is applied to certain portions of the material producing designs or patterns. The dye is applied in a paste of starch, dextrin, or various gums. A single engraved roll is used to apply each color. The engraved depression receives the colored paste from the dye box, the excess being scraped off by a blade (doctor), and prints the color onto the cloth by pressure between a rubber-covered roll. The cloth is steamed to fix the color and prevent spreading. The starch paste may then be washed out, leaving the color in the desired pattern. This description is very brief since there are as many, if not more, variations to printing as there are dyes. There are no wastes from the printing machines and only small amounts from the washing of the cloth. The largest portion of the waste is from the color shop (called color-

shop waste) where the printing pastes are made. The waste consists of washings from color boxes, rolls, tubs, floors, and excess paste and starch. Large volumes of water are used. A new type of dye similar to paint has appeared on the market. The color is mixed with a titanium pigment and printed on the cloth. No washing is necessary, simplifying printing procedure.

Sources, Quantity, and Character of Wastes

It is from the processing and dyeing of textile fabrics that liquid industrial wastes are produced. The dye waste from the carding department consisting mainly of dirt, leaves, sticks, and fragments of the cotton boll, is small in volume and unimportant.

SIZING BATH—SLASHER WASTE

A typical bath consists of 100 pounds of starch and a few pounds of softener per 100 gallons of water. Sizing is applied on the basis of about 60 pounds per 1,000 pounds of goods. No waste is produced except the small amount dumped at the end of a run. A waste is also obtained from the starch kettles which are washed each week. Some examples of slasher wastes are shown on table Ct–2. The wastes from the starch kettles (*a*) represents results on 2,000 gallons of waste used in sizing approximately 210,000 pounds of material. The waste from the slasher machine (*b*) represent results on 1,012 gallons of waste used in sizing approximately 40,000 pounds of material. The waste resulting from sizing is independent of the amount of goods processed, therefore a sewered population equivalent figure based upon 1,000 gallons of waste per day is presented. The average daily discharge may be obtained from which can be calculated the total population equivalent. The sewered population equivalent figure of 2 per 1,000 pounds of product per day is given for purposes of comparison and indicates that the wastes are not greatly significant.

DESIZING BATH

The malt or enzyme steeping bath is the only true desizing waste since sizing removed in the kier is included with the waste kier liquor. A preliminary acid treatment, the gray sour, is small in volume and has a negligible pollutional quality. The desizing bath waste may have a biochemical oxygen demand over 8,000 parts per million although again the volume is small. The volume of wash water varies with individual mills but gives a sewered population equivalent approximating 96 per 1,000 pounds of goods per day, as shown in table Ct–2.

SCOURING OR KIERING

There are a great many variations in mill procedure for scouring cotton. Raw cotton may be kiered and bleached in one process in one machine while cotton cloth is usually kiered in one process, bleached in another and finally soured. Peroxide bleaching is an exception in which case peroxide is added to the kier combining the two processes. In general, it is observed that the strength of waste is dependent upon the degree of treatment which varies with the strength of the kier bath. Although similar kier wastes produce sewered population equivalents that are strikingly close, the wash waters do not check very well.

There are two methods of kiering cotton cloth: The one-boil and two-boil methods. It has been found that more than 50 percent of all cotton cloth is kiered by the one-boil method. Analytical results covering the four following examples are shown on table Ct–2:

(*a*) Boil-off hosiery: 2 percent soap, 1 percent trisodium phosphate.
(*b*) Boil-off knit goods: 2 percent detergents.
(*c*) Kiering, one boil: 2.5 percent sodium hydroxide, 2.0 percent sodium carbonate. Boil 5 hours followed by rinsing

or

3.6 percent sodium hydroxide, 0.4 percent sodium silicate, 0.3 percent trisodium phosphate. Boil 5 hours followed by rinsing.

(*d*) Kiering, two boil:

First boil: 1.0 percent sodium hydroxide, 0.40 percent sodium silicate, 0.15 percent trisodium phosphate. Boil 6 hours.

Second boil: 0.50 percent sodium hydroxide, 0.40 percent sodium silicate, 0.15 percent trisodium phosphate. Boil 5 hours followed by rinsing.

Variations in the population equivalent of the wastes are influenced by the type of kier illustrated by their formulas. The waste from the kier using formula (*a*) is a light scour previous to dyeing, (*b*) waste is somewhat stronger, while (*c*) and (*d*) illustrate the more common kier liquors and will approximate the average waste with a biochemical oxygen demand (5-day, 20° C.) of 7,000 to 9,000 parts per million and a sewered population equivalent of about 110 per 1,000 pounds of goods per day.

BLEACHING OR CHEMICKING

A number of chemicals are used to bleach cotton. Chlorine compounds (chlorine or calcium hypochlorite) are the most common at present although the use of peroxide is rapidly increasing. The cloth is worked cold in an 1.5° to 2° Twaddell solution of chloride of lime (bleaching powder or chemic) comparable to 2 percent chlorine solution.

Table Ct–2 shows two examples of chlorine bleach waste with an average biochemical oxygen demand (5-day 20° C.) of 300 and a sewered population equivalent of 17 per 1,000 pounds of goods per day.

SOURING

After bleaching, the cloth is soured by acid (sulfuric or hydrochloric) of approximately 1° Twaddell or by sodium bisulfite of 1 to 1.5 percent. Two samples of sour waste using 1 percent bisulfite giving results indicated on table Ct–2 showed an average biochemical oxygen demand of 72 parts per million and a sewered population equivalent of 12 per 1,000 pounds of goods per day.

KIER AND BLEACH WASTE

Raw cotton may be kiered and bleached in one process as previously mentioned: The process usually occurs in one machine in the following order: (1) Boil out or wet out, using caustic soda with a soluble oil, (2) rinsing, (3) bleaching, using soda ash and chlorine gas forming the sodium hypochlorite, (4) sour, using sodium bisulfite or sulfuric acid, and (5) rinsing. The average, shown on table Ct–2, of results from several samples, each varying only slightly from the average indicated a sewered population equivalent of 71 per 1,000 pounds of goods per day. As stated, the strength of waste is dependent upon the degree of treatment or strength of the bath. The fact that this figure is less than that given for kiering alone indicates a lighter treatment is involved.

COMBINED WASTES

Many of the kiering, bleaching, souring, and dyeing processes are combined to produce a single waste. Table Ct–2 shows several types of waste analyzed by individual components and then combined to illustrate composite wastes. Of special interest are the boil-off and bleach wastes, both with chlorine and peroxide. The chemicals and other materials used in connection with operations producing these wastes are as follows:

Hosiery mill:
- (*a*) Boil-off: 2 percent soap, 1 percent trisodium phosphate.
- (*b*) Dye: 0.33 percent dye, 12 percent salt, 5 percent oil.
- (*a*)(1) One bath waste, scour and dye: 5.5 percent scour oil, 9 percent salt, 0.35 percent dye.
- (*a*)(2) Boil-off, chlorine bleach: 3 percent soap, 1.5 percent trisodium phosphate, 10 percent chlorine bleach powder.
- (*a*)(3) Boil-off, peroxide bleach and dye: 2.5 percent soap, 2.5 percent peroxide, 3.5 percent oil, 5.3 percent salt, 0.025 percent dye.

Knit goods:
- (*a*) Boil-off: 2 percent detergents, 2 percent peroxide.
- (*b*) Bleach waste: 2 percent chlorine solution for 1 hour.
- (*c*) Sour: 1 percent sodium bisulfite solution.
- (*a*) (*b*) (1) Boil-off and bleach: Not recorded.
- (*a*) (1) Boil-off: 2 percent detergents.
- (*b*) (1) Bleach: 1.5 percent chlorine solution for 1 hour.
- (*c*) (1) Sour: 1 percent sodium bisulfite solution.
- (*d*) (1) Dye waste: 0.05 percent dye, 2 percent salt, 2 per cent leveler.

FINISHING WASTE

The finish applied to cotton is usually starch, waxes, or gums applied as a paste. No waste is produced except the excess discharged at the end of a run. One mill processing 100,000 pounds of cotton per week wasted only 116 gallons per day with the characteristics shown on table Ct–2. Since the waste is independent of the goods processed, the population equivalents have been based upon the gallons of waste produced. The sewered population equivalent of 0.4 per 1,000 pounds of goods per day is shown for purposes of comparison and indicates that the wastes are not significant. Waste (*b*) appears to be more representative and gives a more reliable figure. The biochemical oxygen demand of waste (*a*) is probably below the average.

MISCELLANEOUS PROCESSES

Mercerizing of cotton cloth is brought about by treatment with 40° to 60° Twaddell (roughly, 15 to 30 percent) caustic soda while the cotton is under tension. The waste consists of wash waters, since the caustic bath is rarely dumped. This includes rinses following caustic treatment, several rinses after souring and possibly an ammonia treatment. The data shown on table Ct–2 indicating a sewered population equivalent of 83 per 1,000 pounds of goods per day was obtained by averaging wastes produced by mercerizing chain warp and skein cotton yarn.

Plissé or crepe.—The strong caustic soda used to produce the crinkle is not dumped. The acid rinse and soap and water rinses cause most of the waste which may be slightly acid. Large volumes of water are used. No detailed analyses are available. It is believed that the waste produced by this process is similar to that from mercerizing both in volume and sewered population equivalent.

TABLE CT–2.—*Cotton textile wastes: Example of quantity, quality, and sewered population equivalents of various wastes from the processing of cotton, except dyeing, with typical analytical results*

Waste	Flow, gallons per 1,000 pounds goods	Quality					Sewered population equivalent (biochemical oxygen demand)	
		Color	pH	Total solids		Biochemical oxygen demand 5-day, 20° C., parts per million [1]	Per 1,000 gallons waste per day	Per 1,000 pounds goods per day
				Parts per million	Pounds per 1,000 pounds goods			
	Sizing bath—slasher waste							
(*a*) Starch kettles	95					620	31	3.0
(*b*) Slasher machine	25					590	29	1.0
(*c*) Slasher waste		1,000				1,254	62	
(*d*) Average	60					820	41	2.0
	Desizing bath							
(*a*) Desizing bath	140					8,000		54.0
(*b*) Wash waters	200–1,800					840		42.0
(*c*) Total	1,100					1,750		96.0
	Scouring (boil-off) or kiering							
(*a*) Light scour	3,910		8.6	1,300	42	350		68.0
(*b*) Moderate scour	1,140		9.9	4,100	39	1,450		82.0
(*c*) Average	1,160			9,400	89	1,650		97.0
(*d*) Average	2,320			6,500	127	1,020		120.0
Average (*c*) and (*d*)	1,740			8,000	108	1,240		108.0

[1] In certain cases, particularly average and combined results, biochemical oxygen demand results in parts per million have been computed from sewered population equivalent and flow data reported.

TABLE CT-2.—*Cotton textile wastes: Examples of quantity, quality, and sewered population equivalents of various wastes from the processing of cotton, except dyeing, with typical analytical results*—Continued

Waste	Flow, gallons per 1,000 pounds goods	Quality					Sewered population equivalent (biochemical oxygen demand)	
		Color	pH	Total solids		Biochemical oxygen demand 5-day, 20° C., parts per million	Per 1,000 gallons waste per day	Per 1,000 pounds goods per day
				Parts per million	Pounds per 1,000 pounds goods			
	Bleaching waste							
(a)	1,230					325		20.0
(b)	1,080					270		14.0
(c) Average	1,150					300		17.0
	Souring waste							
(a)	3,690					52		10.0
(b)	3,030					92		14.0
(c) Average	3,360					72		12.0
	Kiering and bleaching waste							
(a) Average	11,500					120		71.0
	Hosiery mill							
(a) Boil-off	3,910	130	8.6	1,300	42	350		68.0
(b) Dye	5,600	525	7.6	3,900	183	290		80.0
(c) Combined	9,510	330	8.1	2,800	225	310		148.0
(a)(1) One bath waste—scour and dye.	8,570	3,000	9.4	4,630	331	210		89.0
(a)(2) Boil-off chlorine bleach.	11,150	120	8.9	1,190	111	360		200.0
(a)(3) Boil-off—peroxide bleach and dye.	15,930	1,500	7.9	1,810	241	410		324.0
	Knit goods							
(a) Boil-off	2,460	450	12.2	8,830	181	1,770		217.0
(b) Bleach waste	1,230	40	10.0	11,360	117	325		20.0
(c) Sour	3,690	20	7.2	1,090	34	52		9.0
(d) Combined	7,380			5,400	332	670		246.0
(a)(b)(1) Boil-off and bleach	1,890		9.6	12,300	194	1,020		96.0
(a)(1) Boil-off	1,140		9.9	4,100	39	1,450		82.0
(b)(1) Bleach	1,080		9.7	16,140	145	270		14.0
(c)(1) Sour	3,030		7.2	1,140	30	92		14.0
(d)(1) Dye waste	1,080		8.0	2,150	19	55		3.0
(e)(1) Combined	6,170			4,600	237	370		113.0
	Finishing waste							
(a)	6	2,500		22,000	1	1,250	62	0.4
(b)							152	
	Mercerizing							
(a)	30,000					55		83.0

DYEING

Direct.—Cotton is usually scoured and bleached before dyeing. A wet-out with water or soluble oil is included with dyeing as noted in the formulas. Varying practices produce similar pollutional quantities regardless of the volumes of water. However, it is difficult to correlate the population equivalents to the poundage when dyeing chain warp and cotton cloth by the continuous process. A general direct dye formula is as follows: Dye, 0.1 to 10 percent; and salt, 3 to 40 percent, followed by rinsing. Comments and explanations on the direct dye waste results shown on table Ct–3 are as follows:

Direct dye formulas:

(*a*) Hosiery: 0.14 percent dyestuff, 2 percent oil, 4 percent common salt or 10 percent glauber's salt (sodium sulfate), average of 10 formulas.
(*b*) Hosiery: Without accessory chemical, formula not reported.
(*c*) Cloth: Average of several samples, formula not reported.
(*d*) Hosiery: 0.33 percent dye, 12 percent salt, 5 percent oil.
(*e*) Hosiery: 0.35 percent dye, 9 percent salt, 5.5 percent oil sour, not preceded by scouring.

Direct black formula:

(*a*) Average of 3 formulas: 6 percent dye (4 to 8 percent), 2 percent oil, 25 percent salt, 2 percent formaldehyde, 0.5 percent acetic acid, 3 per cent soap, 1 percent soda ash.

Table Ct–3 shows sewered population figures per 1,000 pounds per day for direct dye waste to vary from 47 to 92, the average figure being 71, the figure for direct black based on three results is much higher or 133. Direct black does not produce true deep shades so an added treatment of formaldehyde and acetic acid is used to increase the fastness of the dye to washing while a soap and olive oil treatment gives the black a deeper and more lustrous tone.

Basic colors.—Basic dye formulas cover the following ranges:

Boil-out bath: 4 percent S. C. oil, 1.5 percent pine oil.
Tannic acid bath: 1 to 6 percent tannin.
Tartar emetic bath: 1 to 4 percent tartar emetic.
Cold wash:
Dye bath: 0.9 percent dye, 2.5 percent acetic acid.
Finishing bath: 1 percent oil.

A wide variation in results of studies of wastes from basic color dyeing is obtained, probably caused by differences in the boil-out. It may be assumed that the low sewered population equivalent value (*b*), shown on table Ct–3, of 25 per 1,000 pounds of goods per day is for a weak dye bath while the sewered population equivalent of 340 includes a strong boil-off. It is believed that the sewered population equivalent of an average basic dye waste will range from 50 to approximately 100 per 1,000 pounds of goods per day. The average of 100 indicated on table Ct–3 and obtained by giving the high result (*a*) only one-half the weight of the other two results is high for a typical basic dye waste.

Vat dyes.—Vat dye formulas fall within the following ranges: 2–10 percent dye powder, 6–30 percent NaOH (76° Twaddell), 2–7 percent hydrosulfite powder concentrated. An average waste, as indicated on table Ct–3 has a sewered population equivalent of 129 per 1,000 pounds of goods per day.

Sulfur colors.—Formulas for sulfur colors are as follows:

Range: 1 to 20 percent dye, sodium sulfide 1 to 4 times weight of dye, 4 to 7 percent sodium carbonate, 20 to 50 percent salt.
Average: 7.8 percent dye, 11.1 percent sodium sulfide, 4.1 percent sodium carbonate, 21.6 percent sodium chloride.

Table Ct–3 indicates a sewered population equivalent of about 360 per 1,000 pounds of goods per day for sulfur color dye waste.

"Jig" waste from jig dyeing with sulfur black gave a much higher sewered population equivalent of 1,780 per 1,000 pounds of goods per day.

A sulfur black hosiery dye formula is as follows: 8 percent dyestuff, 8 percent sodium sulfide, 2 percent sodium carbonate, 10 percent sodium chloride, 3 percent mineralized olive oil or soap. The reason for the relatively low sewered population equivalent of 115 per 1,000 pounds of goods per day given on table Ct–3 is the customary hosiery mill practice of saving the original dye bath. The used dye bath is made up to strength and reused.

Developed colors.—The same general dye formula indicated for a direct dye bath is used. Formulas for later treatments are as follows:

Diazotizing bath: 1.5 to 2.5 percent sodium nitrite, 3.0 to 5.0 percent sulfuric acid.

Developing bath: Usually 0.45 to 0.90 percent beta naphthol or 0.35 to 0.70 percent phenylene-diamine powder.

Sewered population equivalents shown on table Ct–3 average 120 per 1,000 pounds of goods per day.

Naphthol dyeing.—The formulas used in the operations of naphthol colors are as follows:

Naphthol bath: 0.25 to 2 percent NaOH, 0.25 to 2 percent naphthols.

Dye bath: 0.25 to 2 percent dye base, 1 to 3 percent HCl, 1.5 percent Na_2N, 1.0 percent sodium acetate, 0.5 to 2 percent acetic acid and up to 40 percent salt.

Caustic rinse: 1 to 3 percent soap, 0.5 to 2 percent Na_2CO_3, 0.5 percent NaOH.

Table Ct–3 shows a sewered population equivalent of 59 per 1,000 pounds of goods per day. As in the case of sulfur black dye, wastes from jig dyeing show high results.

Aniline black.—The dye bath is discharged only at the end of a run. Therefore, the constant waste consists of soapy wash water containing some mineral matter and aniline pigment. A typical dye bath is as follows:

	Percent
Sodium ferrocyanide	6.7
Sodium chlorate	3.7
Aniline hydrochloride	13.7

The biochemical oxygen demand of the strong aniline dye vat is approximately 25,000 to 50,000 parts per million. Should the volume dumped at infrequent intervals be fairly large, disagreeable conditions may arise. It must be stated, however, that the aniline dye bath is kept as short (concentrated) as possible. Table Ct–3 indicates that the wash waters from aniline black dyeing have a sewered population equivalent of 41 per 1,000 pounds of goods per day.

Printing.—Color shop waste contains dye paste, starch, gum, thickeners, accessory chemicals, and washings from the rolls, brushes, dye vats, floors, and utensils. Table Ct–3 shows print-shop wastes to have an average sewered population equivalent of 15 per 1,000 pounds of goods per day, with considerable variation in the two figures making up the average.

Waste has been found as follows: The first result (a) was computed from results showing that 151,000 gallons of waste with an average biochemical oxygen demand (5-day, 20° C.) about 60 parts per million (58.5) were produced in processing 100,000 yards of goods. It is estimated that about 7 yards of calico may be made from 1 pound of cotton. Making allowances for heavier material, the average weight of a yard will approximate 3 ounces.

Raw stock dyeing.—Various dyes are used on raw stock, primarily sulfurs, developed, and some naphthols. The dye baths will approximate the formulas previously given. In general about 10 percent dye per weight of raw stock will be used with the customary accessory chemicals. Three samples of waste are given on table Ct–3—developed dye waste, sulfur dye waste, and waste from sulfur, naphthol, and developed.

Yarn dyeing—Indigo.—The machines for the indigo dyeing of yarn have been described. The dye bath is similar to those of the regular vat dyes. The strength of the waste varies with the machine and type of indigo dyeing such as shade, etc. The low population equivalent of the third waste (c) in table Ct–3 is caused by the elimination of the preliminary caustic treatment during the process. This removes the wastes emanating from such treatment and the necessary rinses.

Stripping and redyeing.—Color is removed from cloth by various methods dependent upon the type of dye. Directs are stripped by soda ash, hydrosulfite, or bleaching powder, while basics may be removed by treatment with a fairly strong acid followed by ammonia. A typical strip-out bath is as follows: 5.1 percent soda ash, 3.9 percent strip-out sodium hydrosulfite, 1 percent soap, and two rinses. The dyeing process following stripping is similar to ordinary dyeing. Table Ct–3 indicates that a strong pollutional waste is produced by stripping and redyeing.

TABLE CT-3—*Cotton textile wastes: Examples of quantity, quality, and sewered population equivalents of various wastes from the dyeing of cotton with typical analytical results*

Waste	Flow, gallons per 1,000 pounds goods	Quality					Sewered population equivalent (biochemical oxygen demand) per 1,000 pounds goods per day
		Color	pH	Total solids		Biochemical oxygen demand, 5-day, 20° C., parts per million [1]	
				Parts per million	Pounds per 1,000 pounds goods		
	Direct dye waste						
(a) Hosiery	5, 250		7. 4	1, 900	83	270	70
(b) Hosiery	6, 000		8. 0	1, 300	64	160	47
(c) Cloth	3, 600					510	92
(d) Hosiery	5, 600	600	7. 5	3, 900	183	290	80
(e) Hosiery	8, 570	3, 000	9. 4	4, 600	331	210	89
(f) Average (a) to (e)	6, 400		8. 1	2, 600	140	220	71
	Direct black waste						
(a) Average of 3	10, 000			5, 900	490	260	133
	Basic color wastes						
(a) ½ weight in average	26, 000			870	188	260	340
(b)	8, 300			1, 000	70	60	25
(c)	23, 000			830	159	50	57
(d) Average	18, 000			900	130	100	100
	Vat dye						
(a) Vat liquor	18, 900					140	129
	Sulfur colors						
(a)	5, 450					1, 300	357
	Sulfur black						
(a) Jig	17, 380					2, 000	1, 780
(b) Hosiery	5, 400			4, 300	194	430	115
	Developed colors						
(a) Raw cotton	8, 950					210	100
(b) Spool cotton	10, 350					230	119
(c) Beam warp	13, 250					190	128
(d) Skein cotton	25, 200					100	130
(e) Average	14, 400					170	120
	Naphthol colors						
(a) Naphthol	5, 600					75	21
(b) Naphthol (jig)	3, 900					500	96
(c) Average	4, 800					280	59

[1] In certain cases, particularly average and combined results, biochemical oxygen demand results in parts per million have been computed from sewered population equivalents and flow data reported.

TABLE CT-3—*Cotton textile wastes: Examples of quantity, quality, and sewered population equivalents of various wastes from the dyeing of cotton with typical analytical results*—Continued

Waste	Flow, gallons per 1,000 pounds goods	Quality					Sewered population equivalent (biochemical oxygen demand) per 1,000 pounds goods per day
		Color	pH	Total solids		Biochemical oxygen demand, 5-day, 20° C., parts per million	
				Parts per million	Pounds per 1,000 pounds goods		
	Aniline black—wash waters						
(a) Continuous	8,300					60	25
(b) Process	23,000					50	57
(c) Average	15,600					55	41
	Printing						
(a) Color shop	8,050					60	23
(b) Color shop	1,050					130	7
(c) Average	4,500					95	15
	Raw stock dying						
(a) Developed colors	8,950					220	100
(b) Combined dye house	7,400					280	104
(c) Sulfur including black	4,730					1,400	334
	Yarn dyeing—indigo						
(a) Indigo	9,420	900	9.8			175	82
(b) Indigo	2,340					620	72
(c) Indigo	660	3,500	10.5			600	20
	Stripping and redyeing						
(a) Hosiery	13,200					520	345

SEWERED POPULATION EQUIVALENTS OF COTTON MILLS

There are several methods of obtaining the sewered population equivalents of cotton mills. The best, no doubt, is by analytical results of the liquid waste. When it is impossible or inadvisable to sample and gage a mill waste, a careful survey of the individual processes and detailed analysis of mill procedure is required. This method of calculating the quantity of polluting material necessitates a break-down of the various processes and a further break-down within individual processes. With sound knowledge of the mill procedures and the pounds of goods processed, a relatively accurate population equivalent may be assigned for each 1,000 pounds or fraction processed per day.

Continuous processes, in some cases, must be handled in a different manner. More accurate results may be obtained by using information on the daily discharge and applying the indicated strength of waste to compute the sewered population equivalent. This method is applicable also to waste dumped periodically, such as at the end of the day. Weekly batch discharges and accidental or necessary spills may be extremely significant. Their pollutional quantity may be estimated from the volumes.

Table Ct-4 has been compiled from several sources to show typical variations in cotton mills. Nevertheless, a similarity appears when considering the biochemical oxygen demand results and population equivalents based upon 1,000 gallons of waste. It appears that a population equivalent of 20 per 1,000 gallons per day is an average figure or, in other words, the biochemical oxygen demand of textile mill

waste will average approximately 400 parts per million. A fair estimate of cotton mill waste may be obtained by applying these figures to the total waste discharged.

Another suggested method of correlating plant wastes is based upon the number of workers. This method is the least reliable as shown by the wide variations in table Ct–4. Should it be possible to limit the number of workers to those connected solely to the waste-producing processes, a usable figure may be obtainable. A figure based upon employees has been calculated for textile mills in general and has been found to approximate a population equivalent of 44 per worker. An average figure from the data in table Ct–4 is 26. However, the maximum and minimum vary to such an extent from the average that these figures should be used with extreme care or not at all.

Production may be obtainable only in yards of cloth or dozens of hose. It is advisable to change to a weight basis in these cases. The following data indicate approximate weights of various forms of cotton. The weight of hose, of course, will depend upon type, quality, etc. In general, a dozen pairs of hose will weigh from 10 to 16 ounces. For cotton hose, a pound per dozen pairs is the most appropriate figure. It is reported that from 1 pound of cotton the following may be produced:

	Yards
No. 1 yarn (coarsest made)	840
Warp as fed to an indigo machine	20
Denim	1.5
Gingham	6
Calico	7
Lawn	10
Unbleached muslin, depending on the grade	3.4 to 5.7
Cotton prints and similar cloth	4.6

Many mill operators estimate that 10 percent loss occurs during the processing of raw stock to the final product. However, starch is added to many finished products that may equal or exceed this processing loss.

TABLE CT–4.—*Cotton textile wastes: Examples of biochemical oxygen demand and sewered population equivalents of textile plant composites, showing typical variations*

Nature of process	Approximate number of workers	pH	Biochemical oxygen demand 5-day 20° C. parts per million	Gallons waste per day	Sewered population equivalent (biochemical oxygen demand): Total	Per worker	Per 1,000 gallons per day
(*a*) Cotton thread (bleach, kier, oil, dye)	150	3.3	550	40,000	10,093	7.3	27
		9.6	378	19,000	357	2.4	19
(*b*) Finishing cotton piece goods (bleach, kier, dye, print)	120	9.6	605	274,000	8,239	68.6	30
		6.9	420	180,000	3,745	31.2	21
(*c*) Finishing cotton piece goods (bleach, kier, mercerize, print, dye)	220	9.8	478	438,000	10,405	47.3	24
		7.6	315	360,000	5,635	25.6	16
(*d*) Cotton webbing (bleach, kier, dye impregnate	750	11.1	1,983	220,000	21,682	28.9	[1] 98
		6.3	245	80,000	974	1.3	12
(*e*) Cotton denim (dyeing)	350	------	220	244,000	2,617	7.5	11
(*f*) Cotton (desizing, kiering, bleaching, dyeing, printing, mercerizing, and finishing)	500	------	460	800,000	18,250	36.5	23
(*g*) Hosiery	--------	------	300	125,000	1,900	--------	15
(*h*) Knit goods	--------	------	220	244,000	2,700	--------	11
(*i*) Indigo dyeing	--------	------	600	36,000	1,070	--------	30
(*j*) Average	--------	8.0	400	--------	--------	--------	20

[1] Omitted from average.

POLLUTION EFFECTS

Cotton textile wastes, when introduced into a stream, may deplete the dissolved oxygen, cause turbidity and sludge deposits, create undesirable odor, color the stream water, introduce materials toxic to aquatic life, change the acid-alkaline condition of the stream, increase the temperature, and cause floating

scum. Some of these effects may be of minor importance in individual cases, and the importance of all effects depends on the relative size of the stream.

Textile wastes introduced into a stream exert a demand upon the oxygen dissolved in the water. This demand occurs in two parts, namely the immediate and biochemical oxygen demands. The immediate demand is exerted by reducing agents such as hydrosulfites, sulfides, reduced dye, and forms of organic matter, while the biochemical oxygen demand is caused by bacterial action upon the organic matter. The reduction of dissolved oxygen interferes with normal stream life.

The solids in textile wastes are suspended, dissolved, and colloidal. Neutralization of the waste in the stream causes precipitation of some dissolved and colloidal matter which settles along with the suspended matter. Turbidity is the immediate effect. The settled solids form sludge banks that aggravate local conditions and also prevent fish from obtaining food.

Hydrogen sulfide emanating from sulfur compounds or dyes and from anaerobic decomposition is the primary cause for odors.

Color in itself may not be harmful and may cause little, if any, damage to the streams. However, the appearance of a varicolored river is not pleasant and may cause riparian owners to object, even when no health hazard is present.

Toxic materials such as chlorine, chrome, aniline and copper sulfate inhibit biological activity and destroy fish life.

The reaction of a waste is important because of its influence upon normal aquatic life. Wide variations of the *p*H inhibit normal biological activity, destroy aquatic life and interfere with water treatment plant operation.

High temperatures, which increase biological activity and reduce the oxygen-carrying capacity of the stream, may be a factor in certain cases.

Grease and oil, if not removed, may cause a floating scum, creating an objectionable appearance of pollution and covering the stream and preventing reaeration.

Remedial Measures

Cotton textile waste remedial measures may involve waste reduction measures in the textile plant, recovery practices, equalization of flow, particularly of batch discharges, mixture of waste to secure mutual precipitation, treatment in independent textile waste treatment plants, treatment with sewage in municipal plants and practically any combination of these measures.

REDUCTION MEASURES

A promising and logical procedure for relieving or eliminating waste pollution or waste treatment consists of preventing the production of wastes. There are important and economic possibilities in wastage elimination by adequate plant control.

The reuse of relatively clean wash waters may be practiced. Strong processing liquors can be recovered or used in other places in the mill. In one instance, caustic boil-out liquors were diluted and reused to kier cotton cloth with excellent results. Savings in chemicals and reduction in waste resulted. Prior to the reuse of this strong waste, the municipal treatment plant required an additional 20,000 pounds of sulfuric acid per month for *p*H adjustment.

The reuse of sulfur black dye liquors is customary in the hosiery industry. The dye vat contents is retained, made up to strength and reused. This type of economy should be extended to other dyes and other processes.

Continuous processes produce minimum amounts of waste and should be extended to include all possible processes. Likewise, the judicial use of counterflow principles will greatly diminish the liquid wastes.

RECOVERY PRACTICES

Recovery holds promise for those liquors of high chemical strength such as the caustic mercerizing liquors, caustic boil-off wastes and kier liquors. Mercerizing liquors are usually reused or recovered by dialysis or evaporation. Evaporation is not feasible for kier liquors but dialysis shows promise.

Precipitation of the dye from waste liquor has been tried on an experimental scale. The wasted dye (approximately 10 percent of the original amount) is highly dispersed, requiring efficient precipitation for satisfactory recovery. Both dye and precipitating agents have been recovered. This process is complicated by the necessity of separating the various wastes within the mill.

INDEPENDENT WASTE TREATMENT PLANTS

Chemical precipitation is the most common method of textile waste treatment. This method lends itself to the enormous variations encountered and is the only method by which concentrated wastes can be treated successfully. Adjustment of *p*H may be considered chemical treatment, especially when a precipitate is formed upon neutralization. Large chemical dosages are required to overcome the dispersing agents employed during the application of dyestuffs.

The disadvantages of chemical treatment lie in the sludge disposal problem and cost of treatment. Concentrated wastes require large amounts of coagulants and produce enormous volumes of sludge. The sludge appears to be amenable to drying on sand beds. Cost may be reduced by recovery of the chemicals. A Dutch plant precipitating textile wastes in conjunction with domestic sewage recovers alum, the coagulant, by treating sludge with sulfuric acid; 80 percent of the alum is recovered.

The most common chemicals used in chemical treatment of cotton textile wastes are:

Ferrous and ferric sulfates.	Sulfuric acid.
Aluminum sulfate.	Calcium hydroxide (lime).
Ferric chloride.	Calcium chloride.

Lime has been used to precipitate color shop wastes, while copperas and lime or calcium chloride is best for indigo. In general, copperas and lime are the most universally successful reagents for textile wastes besides being the most economical. Acids or alum should never be used for precipitating sulfur dyes because of the evolution of hydrogen sulfide.

TREATMENT WITH MUNICIPAL SEWAGE

Textile wastes discharged to municipal sewers are usually treated by the municipal sewage treatment plant. Holding tank capacity for 24-hour compositing is virtually a necessity. Poisonous substances should be removed from the waste when subsequent treatment processes involve biological action. It is advisable to have arrangements whereby the mill superintendent notifies the sewage plant operator whenever strong batches of wastes are discharged. Large volumes of textile wastes may require pH adjustment or pretreatment, especially when biological purification processes are used. Proper provision should be made in design of sewers and the sewage treatment plants to handle the waste volume and additional pollution load.

Activated sludge process.—The activated sludge process has been used to treat combinations of sewage and textile wastes. This method provides the best color removal when successfully operated. The volume of sewage must be large and the waste discharge controlled. Pretreatment is oftentimes required by many municipalities. One mill neutralized sulfur dye wastes and aerated to remove hydrogen sulfide prior to discharge into the municipal sewer. Pretreatment with ferric chloride has been used to aid color removal and prevent sludge bulking. One plant requires proportioning of textile waste to sewage flow. pH adjustment, chemical precipitation with alum followed by primary flocculation, reaeration, and then treatment by activated sludge. Results are excellent except when sudden doses of strong wastes appear. Large quantities of suspended solids in the aeration tanks aid color removal. Three percent sulfur dye wastes mixed with sewage have been successfully treated on an experimental basis. At present, one plant successfully purifies a 16 percent textile waste-sewage mixture and expects over 25 percent textile waste from cotton mills in the near future.

Biological filters.—Trickling filters withstand sudden shocks of pH variations and large loadings although color removal may not be satisfactory. Ninety percent purification has been obtained which is similar to treated domestic wastes. Recirculating filters have been used experimentally to treat mixtures of sewage and textile wastes. Strong mixtures can be successfully treated, especially when the pH range of 6 to 8 is maintained.

Combinations.—The most logical method lies between the two previously discussed processes, chemical and biological. The removal of the major portion of the pollutional load is best accomplished by chemical means followed by biological treatment for the residual. In this manner, the shock of the strong waste is absorbed by the chemicals while the pollutional qualities (biochemical oxygen demand) and residual tenacious color is removed by biological action.

MISCELLANEOUS CORRECTIVE MEASURES

Textile wastes are usually hot. Heat exchangers may be installed, recovering heat and lowering waste temperatures. This type of recovery has been overlooked in the textile industry. Storage of the wastes with subsequent mutual reaction and neutralization, possibly with precipitation, reduces pollution. Screening may prevent fiber loss and remove large floating objects. Screens are necessary when pumps are required.

Kier liquor has been successfully digested, producing large amounts of gas. It has been proposed to pipe waste kier liquor direct to the digestion tank of the municipal disposal plant. Allowing for the difficulties of piping the waste, this solution appears practical.

Toxic wastes should be eliminated by separate treatment or lagooning. The cheapest method is to lagoon the waste allowing it to evaporate and seep into the ground.

Concentrated wastes such as slasher waste and color shop (print waste) starch may best be incinerated.

EFFLUENT DISPOSAL

Standards for the discharge of textile wastes have been suggested. These standards are based upon suspended solids, biochemical oxygen demand, total solids, alkalinity and acidity, color, and absence of toxic materials. The treated textile waste should compare favorably in respect to suspended solids, biochemical oxygen demand, and total solids with the effluent from the required domestic sewage treatment unit. A color of 100 or less (platinum-cobalt) has been taken as satisfactory for a plant effluent although this is a rigid standard and imposes hardship upon the disposal plant. The pH should range between 6 and 8, and toxic material should be absent. Solids standards have not been proposed in the United States although they have been suggested in England.

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TEXTILE WASTES

(Not an Actual Plant)

Plant Southern Cotton State Alabama Ref.No. Te-260

City Ford City County Cobert Main Watershed Tennessee

Address 1000 Shore Drive Sub-watershed Cedar Cr. (1/2 mi.)

Informant Mr. W. Blank Title Super. Principal Product Cotton

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	80	250	275
Maximum	144	300	310

Seasonal variation Peak during Spring and Summer

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	Municipal	32,000	40,000	None
Industrial	River	295,000	400,000	"
Cooling	Private Pond	No est.		"

RAW MATERIAL: Lbs. per Yr. Cotton 19,000 lbs./day - Yarn 800 lbs./day

Wool: Grease Scoured Substitutes

Rayon Silk

Chemicals:- Soap Oils

Dye stuffs Bleach Chlorine

$NaCl$, Na_2SO_4, H_2SO_4, $NaOH$, Acetic Acid

PROCESS:- Scoured 18,000 lbs./day Dyed 9500 lbs./day

Bleached 18,000 lbs./day - Print Goods 5000 lbs./day

PRODUCTS:- Cotton Goods 19,000 lbs./day

WASTES:- Quantity 295,000 g.p.d. How estimated Meter Records

Character:- Washings Acid

Process Alkali

Possible spills

Segregation of Strong Wastes

Difficulties

Treatment Lagoon

Analyses:- Number None Date By whom

Appearance

OUTLET:- Where to Cedar Creek

Description:	Size and Shape	Material	Location	Elevation
1.	24" circ.	Tile	Rear of Plant	
2.				
3.				

Gaging possibilities Within mill, manhole in storeroom

Conditions below outlet: Color Noticeable

Turbidity High Deposits Sludge banks

SANITARY SEWAGE: Disposal Raw to Creek Persons tributary 290

REMARKS

Survey by John Jones Date 2-1-41

Process and wastes (field notes)

Wastes	Form of cotton	Pounds per day	Volume of waste	Chemicals used, amounts	Type 8 capacity machine	Preliminary treatment	After treatment and rinses
			Gallons per day				
Slashing	Warp	12,000	300	760 pounds starch	Continuous	(Batches discharged daily.)	
Desizing	Cloth	2,000	4,000		Enzyme steeping	Wet-out	2 rinses.
Kiering	do	18,000	38,000	540 pounds $NaOH$; 54 pounds Na_3PO_4, 54 pounds Na_2SiO_3	Pressure kier-1 boil; 3,000 gallons-9,000 pounds		1 rinse.
Bleaching	do	12,000	96,000	250 pounds Cl_2	Continuous	Rinse	Rinse.
Souring	do	12,000	42,000	H_2SO_4	do		Do.
Mercerizing	do	2,500	75,000	Caustic (Conc); Acid rinses	Caustic (vat); Acid rinse—continuous		1 acid rinse. 2 after rinses.
Miscellaneous:							
Dyeing		9,500					
Direct	Cloth	5,000	18,000	1 percent dye, 30 percent salt			Rinse.
Vats	do	2,000	40,000	5 percent dye, $NaOH$, hydrosulfite			
Sulfurs	do	2,000	20,000	10 percent dye, 10 percent Na_2S, 40 percent salt	Continuous		
Developed	Raw stock	500	4,500	10 percent dye, 10 percent Na_2S, 40 percent salt	Batch process		
Etc. print shop	Cloth	5,000	25,000		(No waste from machine—washing of vats, buckets, etc.)		
Finish			200	Starch	Continuous	(Dumped in batches.)	
Periodic							
Spills							

TYPICAL INSPECTION REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I-11

INDUSTRIAL WASTES

River Mileage Index No. *T 260*

Type of Plant: *Textile—Cotton.* State: *Alabama.*
Name of Plant: *Southern Cotton Company.*
Municipality: *Ford City.* Main Watershed: *Tennessee.*
County: *Colbert.* Subwatershed: *Cedar Creek (½ mile).*
Address: *1000 Shore Drive.*
Source of Information: *Mr. Will Blank, Superintendent.*
Plant Operation:
Av. 80 hours per week, 250 days per year.
Max. 144 hours per week, 300 days per year.
Employees Av. Office 11, plant 275.
Max. Office 14, plant 310.
Seasonal Variation: *Peak during spring and summer.*

(Survey report continued on next page)

Survey by *John Jones.* Date: *2/1/41*

Sewered Population Equivalent Computation:
Factors used: *Computed from break,down of mill processes.*
B. O. D. ______ Suspended solids ______.
Sewered population equivalent* based on B. O. D.: *3900.*
Sewered population equivalent* based on suspended solids ______.
Remarks: Factors in "Cotton Guide".

Computation by *John Doe.* Date: *2/10/41.* Cincinnati Office

NOTE: This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
*Rounded to nearest 100.

(*Typical inspection report continuation sheet*)

Southern Cotton Company, T 260
Ford City, Ala.

Water Supply:
Drinking—from city ____ Av. 32,000. Max. 40,000
Industrial—River ____ Av. 295,000. Max. 400,000
Raw Materials:
Raw Cotton ____ 19,000 lbs. per day
Yarn (Indigo dyed) ____ 800 lbs. per day
Accessory chemicals typical of cotton processing mills. Volumes may be estimated from formulas.
Products:
5,000 lbs. per day print goods.
9,000 lbs. per day dyed material.
4,000 lbs. per day bleach finished.
1,200 lbs. per day Denim.

19,200 lbs. per day Total output.

Wastes: Total Metered—295,000 gals/day.

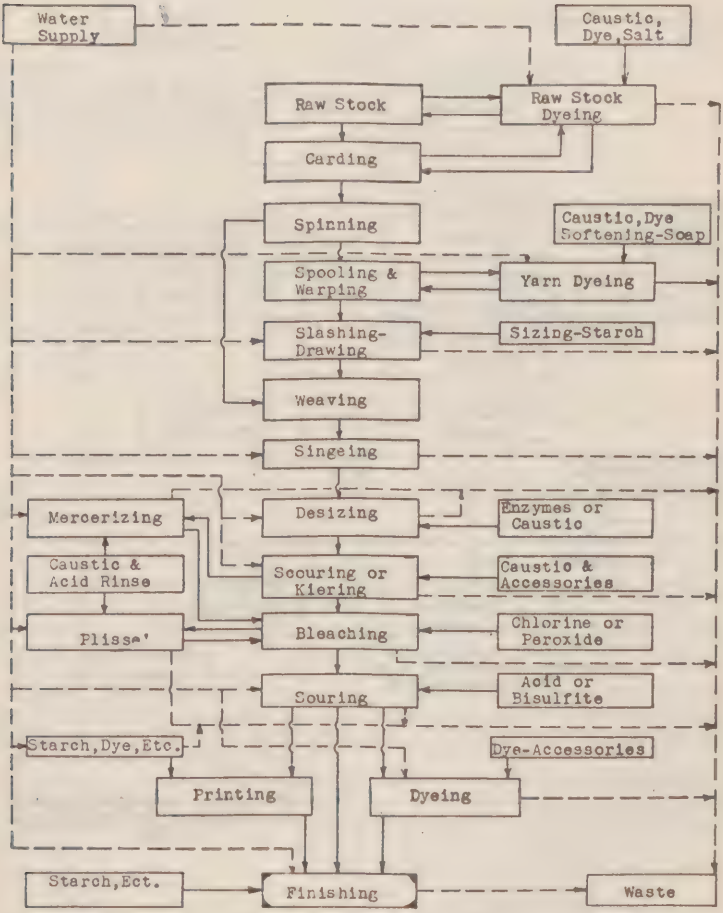
Process	Lbs. of goods	Gallons	P. E.
Slashing	9,000	300	12
Desizing	2,000	4,000	192
Kiering	18,000	38,000	1,764
Bleaching	12,000	75,000	180
Souring	12,000	30,000	150
Mercerizing	700	21,000	58
Direct dyeing	5,000	18,000	460
Vat dyeing	2,000	40,000	260
Sulfur dyeing	2,000	20,000	720
Developed dyeing (raw stock)	500	4,500	50
Print works	5,000	25,000	75
Finish	------------	200	20
Total	------------	276,000	3,941

(Typical inspection report continuation sheet)

Outlets: 24″ circular tile leaving the plant at the rear loading platform. This pipe carries the waste from the entire plant. Best possibility for sampling and gaging is within the mill. Manhole accessible in stockroom.

FLOW DIAGRAM

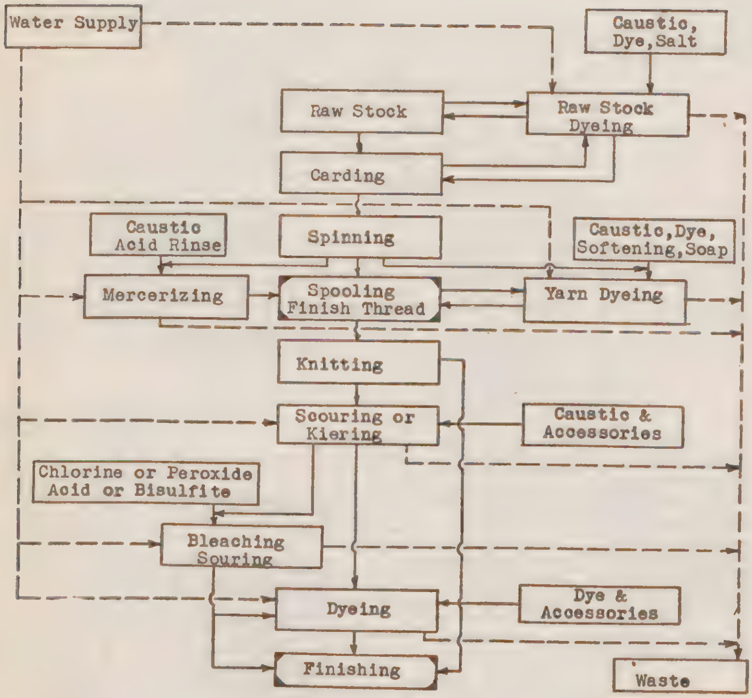
COTTON PIECE GOODS



Ohio River Pollution Survey
U. S. Public Health Service

FLOW DIAGRAM

COTTON THREAD AND KNIT GOODS



Ohio River Pollution Survey
U. S. Public Health Service
1942

APPENDIX VI OF SUPPLEMENT D

DISTILLERY

An Industrial Waste Guide to the Distillery Industry

CONTENTS

LIST OF TABLES

Abstract

The production of alcohol by fermentation and distillation is accomplished with the use of corn, rye, and malt for the production of whisky; and molasses or cane syrup for the production of commercial or industrial rum and industrial alcohol.

Wastes developed in these processes are highly organic, acid, and contain a major portion of their solids in solution. Besides the carbon dioxide recoverable from fermentation, aldehyde and fusel oil are products of rectification.

Disposal of wastes is commonly by stock feeding, evaporation or discharge to the streams. Evaporation, in use at a number of large distilleries, recovers valuable spent solids from grain distillery waste, for use as stock feed, while potash and nitrogen are recovered from molasses or cane syrup distillery waste.

Various treatments of distillery wastes have been attempted. Chemical precipitation has met with but little success. Anaerobic digestion, followed by trickling filters, has shown promise on a pilot-plant scale but is not in commercial use in the distillery industry.

Table D-1 gives the strengths of various wastes discharging from distilleries, as the most up-to-date data available. Grain distillery thin slop strength applies to distilleries using corn and returning one-third of the screened slop to the fermentor.

TABLE D-1.—*Strength in parts per million and sewered population equivalents of various distillery wastes per thousand bushels of grain mashed daily or per 5,000 gallons of 100-proof spirits produced daily*

Waste	Analyses—parts per million		Sewered population equivalents [1]	
	Biochemical oxygen demand (5-day 20° C.)	Suspended solids	Biochemical oxygen demand	Suspended solids
	Grain distillery (corn)			
Thin slop	34,000		55,000	
Tailings	740		50	
Evaporator condensate	1,200		1,500	
Combined wastes [2]			3,500	2,260
	Molasses distillery			
Molasses slop	33,000	3,270	60,000	5,000

[1] Based on 0.168 pound of biochemical oxygen demand (5-day 20° C.) per capita.
[2] No intentionally discharged slop included.

Description of Process

The process of distilling raw spirits is much the same in all plants, although there may be considerable variation in the ingredients used. The description which follows, arranged as nearly as possible in sequence, covers the practices in a bourbon or typical Kentucky distillery with occasional comments as to comparison with similar processes.

MILLING

The production of distilled spirits usually is accomplished from grain, either rye or corn, separately or in combination. As a preliminary step, dust, stones, chaff, husks, and foreign matter are removed from the grain by the use of screens or pneumatic machines. The refuse may be retained in bags for sale to farmers or feed merchants, or discharged into a vessel of water for final disposal to the sewer. The grain is then ground to a size desired by the individual distiller. After milling, it is stored temporarily in bins or scale hoppers. Storage facilities are usually maintained for grain as received and milling takes place the day the grains are to be used.

MASHING, COOKING, AND COOLING

From the scale hoppers or bins the grain is discharged into the mash tub or cooker. In many plants, particularly the smaller ones, the open mash tub is used. It is equipped with steam coils or direct steam jets for heating purposes, cooling coils, stirring mechanism, and water facilities. The vacuum type cooker, generally used at the larger plants, is a covered dome-shaped vessel with direct and indirect steam for heating, cooling coils, water, vacuum, and pressure facilities. An opening in the dome permits addition of the mashing ingredients.

The quantity of water added to the milled grains depends upon whether direct or indirect steam is used in heating and usually is from 20 to 24 gallons per bushel of grain mashed. The length of time and temperature required in mashing is dependent upon the grains used. If corn is the predominating ingredient instead of rye, the temperature must necessarily be higher with the time longer, in order to reduce the grains to the pasty form required for saccharification. This temperature variation ranges between 158° to 200° F. When thorough digestion is complete, the temperature is reduced to approximately 120° F. and the malt is added. The diastase, an enzyme of the malt, attacks the ruptured starch cells and converts them into dextrose and maltose sugars. The quantity of malt varies between 10 and 15 percent of the total batch. Vacuum cookers permit cooling under vacuum and digestion under pressure.

After the malt has been added and the saccharification is complete, the batch is cooled down to about 80° F. in the cooker or, if the cooker is needed for the

following batch, this final cooling is accomplished in a drop tub. The stirring necessary in all cookers and tubs to keep the mash from lumping is usually carried out by the use of mechanically operated paddles.

YEASTING

Yeasting, or the addition of yeast to the mash, is carried on with the utmost care and supervision. The success of this important step depends largely upon the sterilization of the utensils and machinery through which it is accomplished. Many distillers have attributed their success in producing a particular brand of whisky to the activities carried out in the yeasting room, often in the utmost secrecy. In general, a pure culture yeast is used to propagate a culture that is particularly suited to the type of fermentation practiced, be it of a sour or sweet mash consistency.

The yeast mash or starter mash is a batch of small grains, as malt and rye, prepared and saccharified as in the large cookers previously explained, but with more care in processing. After the final cooling to approximately 120° F., it is inoculated with a lactic-acid bacteria and allowed to work over a period of 24 to 36 hours. When the proper degree of acidity has been reached, part of the batch is removed to be used as a starter for the succeeding batch. The pure culture yeast is now added to the batch in sufficient amount for inoculation and, after several hours' working, the batch is added to the fermentors. The quantity of yeast mash may vary, but generally about 1 to 2 pounds of rye and a like amount of malt are used per bushel of grain in the mash.

MALTING

The preparation of malt in this country is accomplished by regular malting companies, actually far removed from the distilleries, and located near or in the grain belt.

Any grain can be used for preparing malt, but generally barley is the most suitable. The process consists of grinding the grain to the desired fineness and, by the addition of moisture, developing the germ to the highest degree of activity to convert starch to sugar. The resulting meal is dried and bagged for shipping. The economical quantity of malt necessary depends upon its diastatic power, soluble starch available, and ability toward liquefaction.

FERMENTATION AND BACK SLOPPING

Fermentation is generally accomplished in large, wooden, straight-sided, open tubs, located in a building with heating facilities. Some plants are equipped with stainless steel or glazed tile fermentors although the latter has not proven successful as the lactic acid produced in fermentation attacks the cement joints between the tiles making repairs frequently necessary. The covered fermentor is now being used in many plants for the recovery of carbon dioxide gas given off in fermentation, to manufacture liquid and solid (dry ice) carbon dioxide, and to prevent the loss of 1 to 2 percent of alcohol by evaporation.

The fermentation is carried on at room temperature averaging about 70° F. for periods of either 72 or 96 hours. The mash starts at a temperature of about 72° F. and approaches 86° to 90° F., when maximum activity is reached.

The cooker mash is pumped to the fermentors from the drop tub through the cooling coils or cooling tank, and the yeasting mash is added by gravity to the same vessel. In order to increase the activity of fermentation, it is necessary to dilute the saccharified mass with sterile water or slop which has been through the process of distillation and, therefore, is available in a sterile condition. Usually sterile slop is screened, cooled to the fermentation-starting temperature, and used. This slop, containing lactic acid and considerable dissolved solids, affords essential bacterial food for fermentation. The procedure is known as back slopping or setting back, and the quantity used averages about one-third of the total fermenting batch. However, if the slop, when dealcoholized, is to have solids recovery possibilities, it is of utmost importance that the density of the fermenting wort be kept high by reducing the amount of slop back. The fermentors usually carry a volume of about 45 gallons per bushel of grain used, including a one-third slop return. This may be varied in accordance with the practices of the distiller.

After fermentation is complete, a rich amber colored liquor remains containing 5 to 8 percent alcohol, fusel oil, aldehyde, water, acids, and solid matter. This liquor, generally spoken of as beer, is now run to the beer well where agitation is available and where it can be pumped at a uniform rate to the distilling equipment.

DISTILLATION

The distillation is accomplished in one of two types of distilling apparatuses known as the continuous multiple type and the three-chamber or batch type. Many prefer the latter as it is claimed that a richer, heavier-bodied product, is produced. The multiple type is more economically operated, requiring less steam and attention.

The continuous still is a high, small-diameter column fitted with many perforated plates, equipped with down pipes alternating between plates from one side to the other so that as the mash enters about one-fourth of the way down from the top and starts on its downward course a zigzag path is maintained. Before entering the still, the beer passes through a beer heater which raises the temperature to a point, where, upon entering the first still plate, an economical evaporation will become effective. The live steam is administered through the bottom and passes up the perforations in the plates, thus heating the beer and driving off the alcohol. The vapors escaping from the still are directed to the heat exchangers in connection with the beer heater. Some vapors, on condensing, are refluxed to the topmost section of the still for reevaporation. The remaining vapors pass on through the condensers and emerge in liquid form, known as low wines at approximately 105 proof strength. The remaining mash, known as slop, continues to the bottom of the still and escapes to the disposal plant.

The three-chambered or rye whisky still, as it is sometimes called, consists of a column similar to but shorter than the continuous still. It has three reservoirs, one above the other, where batches of the beer can be boiled off in stages of 15 to 20 minutes for each chamber, starting with the top and continuing until the bottom chamber is reached. The vapors are directed to a condenser and the liquid collected in the low wine tank. Slop is released for disposal at the bottom of the column.

In both type stills the operation is continued until the fermented beer has been passed through the distilling apparatus. The final beer going through the distilling apparatus, after a day's run, has a low density due to the dilution with water in washing down the fermentors, beer well, and distilling apparatus. The quantity of this water will average between 50 and 100 gallons per fermentor and similar amounts for the beer well. The apparatus wash will possibly add 200 to 300 gallons additional.

RECTIFYING

The vapors coming from the main still, when condensed, contain alcohol, water, aldehyde, fusel oil, and other impurities. These impurities, which are objectionable, must be separated from the alcohol by further processing. This is accomplished by distillation at lower temperatures, and at some plants is the source of aldehyde and fusel oil byproducts. At the majority of distilleries, however, this distillation is carried on only so far as to free the alcohol from the largest percentage of these products. In these plants the doubler is generally used either by the continuous process or the batch method. The doubler is a closed kettle equipped with heating coils, vacuum outlets, and inlet lines. In the continuous process the vapors partially condensed are freed at the bottom of the kettle and allowed to pass into a body of liquid held at the bottom of the doubler. This liquid is maintained at a temperature capable of volatilizing the alcohol under vacuum. The vapor is directed to condensers which are water cooled, and emerges as liquid known as high wines at approximately 110 proof. The batch doubler, which is similar to the continuous type, collects all the low wines from the day's run or until the capacity is reached before beginning the distillation.

Many variations in rectifying are practiced. Some distillers prefer using an additional rectifying column on the main still for the second distillation, others using the doubler type, reroute a percentage of the low wines through the main still with the balance going its usual course.

Where increased proof is desired and byproducts such as aldehyde and fusel oils produced, a heating vessel such as the doubler is used in conjunction with a rectifying column, dephlegmators and condenser especially designed to separate the various volatile heads. This produces a spirit alcohol of 190 proof, which may be used industrially or for cutting and blending whiskies.

In rectifying with the doubler by either the continuous or batch methods, water and impurities are left behind in the form of a colorless liquid known as lutter water or tailings. This is often discharged to the sewer after a day's run but in some plants is run through the main still the following day ahead of the fermented mash, and passes out through the slop discharge. The quantity produced varies

with the efficiency of the distilling apparatus, density of slop, and with the care in operation. An average figure will approach three-quarters to 1 gallon per bushel of grain mashed.

CUTTING, AGING, BLENDING, AND BOTTLING

The high wines coming from the final condensers may be reduced in proof according to the desires of the distiller. This may be accomplished by adding distilled water, and is known as cutting.

In order to produce a mellow palatable beverage, suitable to the demands of the consumer, an aging process is carried out by using oak barrels which may or may not be charred on the inside. Usually the charred type is selected and the aging process carried on from 2 to 8 years. As the barrels are filled they are stored in warehouses, with the proper ventilation and under controlled temperature. In the aging process the alcohol gives up its impurities to the walls of the barrel and in turn absorbs the color known as whisky brown, thus causing a shrinkage of the volume of whisky and an increase in the proof strength.

The bottling department is generally located in a building removed from the main distilling operations. The operations of cleaning, filling, capping, and labeling are usually automatic although some plants resort to hand operations on part or all of these functions. Bottles consisting of quarts, fifths (of a gallon), pints and half-pints are the usual sizes. The cleaning machine either is a water spray or air blower type from which the bottles go to the filler, capper, labeler, etc.

In preparing the whisky for bottling, the barrels are emptied into a tank through a filter where the whisky is tested for proof and increased or decreased as desired, distilled water being used for cutting or reducing, and 190 proof spirits added for increasing the strength. Blending, carried on at this time, consists of mixing various aged whiskies to produce a flavor particularly bodied to suit the demands of the consuming public.

GOVERNMENT REGULATIONS

In the distilling industry, where alcohol spirits are produced, Government regulation has been found necessary and successful to reduce the loss due to theft and leakage, in order to accurately tax the amount of distillation. For this reason, every distillery has one or more Government employees who must check the amount of raw material used against the alcohol yield, check the amount going to and from storage, amount bottled, and make various other necessary records. All vessels used in processing, beginning with grain hoppers, cookers, kettles, tubs, stills, fermentors, etc., must be plainly marked as to capacity; valves, couplings, joints, etc., must be securely sealed, beginning with the main still and ending on the final condenser; buildings containing whisky or alcohol securely locked and fastened; painting of pipes, water, steam, distilled water, slop, etc., various colors so that they can be followed easily; and many other necessary steps in order to account for the maximum possible distillation.

RUM DISTILLATION

Although this guide has been particularly prepared with reference to the manufacture of rye, corn, or bourbon whiskies, it is applicable, in part, to the production of industrial rum or commercial alcohol from black strap molasses and beverage rum from sugarcane. As no grain is used in this processing, the steps preceding the fermentation are much simpler and quicker, sulfuric acid being used to invert sucrose to glucose and levulose by chemical action. The quantity of sulfuric acid used averages 5 gallons per 1,000 gallons of molasses. Byproducts of dealcoholized molasses wastes in recovery plants consist of potash and nitrogen. Molasses before fermentation is generally diluted in ratios of 1 to 5 or 1 to 3, depending upon whether recovery practices are to be carried out after distillation.

RAW MATERIALS AND PRODUCTS

WATER SUPPLY

Water supply is an important item in the manufacture of alcohol or beverage spirits. The bulk of the water used is for cooling purposes and the best source of this supply is from springs or wells that have a low temperature. This requirement, however, has been somewhat changed in recent years, due to the use of refrigeration. In this case surface supplies have been found satisfactory.

Although process water consumes a small portion of the supply, it is desirable that this water be from springs or deep wells that are high in sulfates. This characteristic increases saccharification and fermentation, and thus, it is claimed, produces a beverage of better flavor.

The uses of water in a distillery may be varied, but the general major functions include cooling and condensing, processing, and washing floors and equipment. Minor uses consist of grain-cleaning wash, bottle cleaning, distilling water, power-house supply, and sanitary requirements.

Cooling and condensing water varies between 300 and 600 gallons per bushel of mashed grain and approximately 180 gallons per gallon of sirup processed. These figures are general and may vary considerably at some plants where activities vary or equipment is inefficient.

Process water is used in preparing the mash and yeast for fermentation and usually is about 20 to 22 gallons per bushel in grain distilling. Molasses or cane sirup may be diluted to 1 to 3 or 1 to 5, depending upon the use of final slop, the maximum dilution being used where recovery of byproducts is not practiced.

Washing water used on equipment and floors is dependent on the lay-out of plant and the desires of the operator. It may reach considerable proportions in some plants. Grain-cleaning wash is the water used to absorb the dust and chaff cleaned from grain. Few plants use water for this purpose.

GRAINS

Raw materials consumed in the distilling industry consist chiefly of grains. Table D–2 lists these materials and also shows the theoretical and practical yield.

TABLE D–2.—*Theoretical and practical yield at distilleries*

	Pounds per bushel	Fermentable sugar and starch		Yield in proof gallons [1] per bushel	
		Percent	Pounds per bushel	Theoretical [2]	Practical
Barley	48	65.5	31.4	5.41	4.50
Malt	34	60.6	20.6	3.55	3.00
Wheat	60	64.8	38.9	6.71	5.90
Maize (Indian corn)	56	66.0	36.9	6.36	5.00
Rye	56	59.3	33.2	5.72	4.75

[1] A 100-proof gallon is a gallon of "that alcoholic liquor which contains one-half its volume of alcohol of a specific gravity of 0.7939 at 60° F." 100 parts of 100-proof spirits contain 50 parts of alcohol and 53.71 parts of water by volume or 42.49 percent of absolute alcohol by weight. 100-proof spirit has a specific gravity of 0.93426 at 60° F. referred to water at 60° F.

[2] The theoretical amount of starch required to produce a proof gallon is 5.8 pounds.

The quantities of raw material and products in a typical grain distillery are summed up in table D–3.

TABLE D–3.—*Typical units per bushel mashed*

Unit	Total	Dry weight
Corn and/or rye grain	0.9 bushels or 50.4 pounds	44.8
Malt	5.6 pounds	5.0
Proof-gallons	5 gallons	
Back slop (thin)	14 to 17 gallons	
Water (process)	20 to 24 gallons	
Water (cooling) [1]	30 to 600 gallons	
Total spent slop	42 to 51 gallons	
Total slop for disposal	28 to 34 gallons	
Total thin slop for disposal	25 to 27 gallons	

[1] Cooling towers may be used where supply is limited. In this case make-up water will average approximately 30 gallons per bushel.

MOLASSES OR CANE SIRUP

The amount of raw material and products in a rum or commercial alcohol distillery per gallon of raw material and per 5 gallons of 100-proof spirits, comparable to table D-3 is shown in table D-4.

TABLE D-4.—*Typical units in molasses or cane sirup distillation*

Unit	Gallons: Per gallon of raw material	Gallons: Per 5 gallons 100-proof spirits
Molasses or cane sirup	1.0	6.7.
Proof gallons	.75	5.0.
Water (process):		
Recovery of spent slop byproducts practiced	3.0	20.0.
Nonrecovery of spent slop byproducts	6.0	40.0.
Back slop	1.2 to 2.4	8 to 16.
Total spent slop:		
Recovery of spent slop byproducts practiced	3.25	21.8.
Nonrecovery of spent slop byproducts	6.25	41.9.
Water (cooling) [1]	180.0	1,200.0.

[1] Cooling towers used where supply is limited.

SEASONAL VARIATIONS

Many distilleries operate only during the winter months. Cold water is readily available in winter for cooling purposes and warehouse stocks can usually be replenished with part-time operation. Pollution problems are also less acute. Six months' operation is quite common. Other distilleries operate on a 12-month basis but at reduced capacity.

EMPLOYEES

The number of employees required is subject to considerable variation. From 20 to 60 employees per 1,000 bushels capacity are typical.

SOURCES AND QUANTITY OF WASTE

MILLING

In milling the grain and preparing it for mashing, some distilleries use screens and pneumatic machines to exclude the dust, chaff, stones, sticks, etc., from the finished meal. In order to dispose of this foreign matter and thus keep the dust from spreading through the mill, this is often discharged to a tank of water and is water-carried to the sewer. Another way of disposal is to collect it dry in bags and use it for poultry feed. It is apparent that the quantity of this material will depend on the cleanliness of the grain.

YEAST ROOM

Cleanliness in the yeast room is important and demands special attention. Here the yeast is prepared and cultures developed. During the process of yeasting, some small grains may find their way to the sewer in small amounts. As many tubs are required, washing and sterilizing of equipment produces a large waste discharge carrying yeast, grain, and mash, and having a high oxygen consuming effluent. Waste flow may be from 5 to 8 gallons per bushel of total grain mashed.

EQUIPMENT WASHES

Equipment washes include all processing and sterilization beginning with mashing and ending with fermentation, including cookers, mash tubs, drop tubs, fermentors, flake stands, beer well, and distilling apparatus. After each run, or as equipment is through functioning for the day, it is given a final scrubbing with steam and water to clean out solids remaining after the wash-down. This extra wash and sterilization carries to the sewer portions of mashed grain and fermented beer. A fair estimate will approach 500 gallons daily at plants up to 1,000 bushels capacity with double this amount or 1,000 gallons on plants above 1,000 bushels and not exceeding 3,500 bushels.

TAILINGS OR LUTTER WATER

The tailings or lutter water, which includes the aldehyde and fusel oil retained in the doubler that is used in most plants, is quite often discharged to the sewer although some plants rerun it through the main still. In this case it finds its way to the slop discharge. It is low in solids and oxygen demand. The quantity produced will depend upon the condition of the fermented beer, operation and efficiency of the main still, refluxing appurtenances and finally the doubler itself. The estimated quantity of this waste is between three-quarters and one gallon per bushel of grain mashed.

SLOP EFFLUENTS

The dealcoholized slop as it comes from the still is high in solid matter, approximately 50 percent of which is in solution. This effluent, averaging 42 to 51 gallons per bushel mashed, is passed over a double-O punched hole screen, through which passes sufficient thin slop to make up the required quantity for setting back to the fermentors. The balance of the waste or whole slop of 28 to 34 gallons per bushel is either discharged, sold to farmers, fed to cattle, treated for recovery of solids, or used for irrigation.

If recovery is practiced, the slop is run over more double-O screens until the moisture content is such that the screenings will not flow. From here the screenings go to a drag box; which is a mechanically operated machine, using an inclined screen, that reduces the moisture content to approximately 90 percent. Screenings then pass to a continuous press where a revolving belt aids in further reducing the moisture content. The press cake, as it is now called, continues on to a revolving steam drier, which delivers the spent grains at a moisture content usually around 5 to 7 percent, although this may be varied as required. The spent grains recovered, average from 8 to 10 pounds per bushel of total grain mashed. They are valued as a stock food, being used mostly as blending material.

The thin stillage collected from the screens, drag box, and press are disposed of by any of the ways listed relative to the disposal of thick slop. This thin effluent represents approximately 26 to 28 gallons per bushel of grain mashed.

SPILLS

Even though satisfactory slop-disposal practices may be followed at a distillery, there is often a slop loss to the sewer due to spills or careless handling, breakage of equipment and damaged grain or yeast cultures. Serious spillage may take place at the sales tanks where slop is dispensed to farmers. Small barrels or tanks, used to transport the slop, often run over and clean-up water may be strong. The amount of spill is normally low but may reach large proportions at times.

CHARACTER OF WASTES

SOLID MATTER

The whole slop discharged from the still in the manufacture of grain alcohol and practicing back slopping has a solid content of approximately 6½ percent. Where screening and drying of spent grains are practiced, the removal of 2½ percent of grain leaves an approximate 4 percent of total solids for the thin slop.

Tables D–5 and D–6 are presented to show the constituents of the raw material and waste in a grain distillery.

TABLE D–5.—*Average analyses of corn and rye (based on 114 analyses of corn and 57 analyses of rye) in percent*

Constituent	Corn	Rye
Water	10.0	8.7
Nitrogen substance	10.5	11.3
Fat	5.2	1.9
Carbohydrates	70.7	74.5
Fiber	2.1	1.5
Ash	1.5	2.1
Total	100.0	100.0

TABLE D-6.—*Solid matter of corn and rye in distillers slop in percent of original grain*

Constituent	Corn	Rye
Nitrogen substance	10.5	11.3
Fat	5.2	1.9
Carbohydrates	15.7	29.5
Fiber	2.1	1.5
Ash	1.5	2.1
Total	35.0	46.3

The slop from molasses distilleries contains very little suspended matter and about 20 percent total solids. The tailings from the doubler or rectifying still, which is colorless and has a grain mash odor, is very low in total solids. An actual analysis gave 200 parts per million 0.02 percent.

ACIDITY

Slop produced in the grain distillery is highly acid and causes serious damage to operation machinery and handling equipment. Screens in presses and drag boxes must be renewed from time to time because of its chemical action. The acidities average 12,000 to 15,000 parts per million and the pH value is about 3.8.

POPULATION EQUIVALENTS

The population equivalent factors of wastes from distilleries, based on biochemical oxygen demand and suspended solids may be shown for undiluted effluents and for the total combined discharges, which will include all cooling and condensing waters.

Table D-7 gives a typical set of analyses on several waste effluents and table D-8 gives typical analyses of combined wastes.

TABLE D-7.—*Analyses of various wastes*

Determination [1]	Thin slop (grain)	Tailings	Evaporator condensate	Slop (molasses)
Acidity	11,900			
pH	3.7			
Total solids	48,300	264		
Volatile solids	45,300			
Suspended solids				3,270
Chlorine demand	541			
Biochemical oxygen demand (5-day)	34,000	735	1,230	33,000

[1] Results in parts per million except pH.

TABLE D-8.—*Analyses of combined wastes in grain distilleries*

Determination [1]	Plant A	Plant B	Plant C
Percentage of thin slop discharged	3	37	(2)
Alkalinity	278	452	186
Acidity			
pH	7.2	7.3	7.5
Chlorides	27	25.0	4.0
Total solids	742	1,838	618
Volatile solids	414	1,200	356
Total suspended solids	360	1,208	221
Volatile suspended solids	331	1,081	166
Chlorine demand	15.0	12.8	2.9
Biochemical oxygen demand, 5-day, total	250	2,800	228

NOTE.—Wastes at plants A and B had been limed.

[1] All results in parts per million except pH and slop discharged.
[2] None intentionally.

Average population equivalent based on biochemical oxygen demand and suspended solids is shown in table D-9 for individual effluents and combined wastes.

TABLE D-9.—*Population equivalents of various wastes*

Waste	Sewered population equivalent — Based on biochemical oxygen demand	Sewered population equivalent — Based on suspended solids
	Grain distillery (per 1,000 bushels mashed daily or per 5,000 gallons, approximate, proof spirits)	
Thin grain slop	55,000	
Tailings	50	
Evaporator condensate	1,500	
Combined grain distillery wastes [1]	3,500	2,260
	Molasses distillery (per 5,000 gallons proof spirits)	
Molasses slop	60,000	5,000

[1] Does not include any intentionally released slop.

POLLUTION EFFECTS

The chief effect of distillery waste pollution on streams is one of deoxygenation. Operation during the winter months, when temperatures are low and flows are high, tends to reduce complaints. Fish life near the sewer outfall is reported to flourish, being more plentiful than at other places in the stream. However, at lower points the suspended matter is deposited and at low flows the stream becomes septic and odors are offensive.

The effects of distillery wastes are pronounced in the vicinity of plants that are attempting to dispose of the slop by feeding to cattle corralled near or within several miles of the plant or by lagooning or irrigation to the land. In such cases the cattle waste or the slop washing to the stream may cause a serious pollution problem. However, the most serious objection and the common cause for complaint is fly breeding and obnoxious odors.

REMEDIAL PRACTICES

SCREENING AND DRYING

The process of screening and drying slop in a grain distillery involves trough screens, drag box, press, and drier. Solids are reduced from 6½ percent in the whole slop to 4 percent in the thin or screened slop. The spent grains recovered have a value (1941) of approximately $22 per ton, and the practice of recovery of spent grains is found in practically all distilleries.

CATTLE FEEDING

The disposal of slop by cattle feeding at or near the plants has caused many complaints due to odors and due to effluents from pens discharging to streams. The practice has been to feed all slop produced to cattle, averaging one animal to every bushel of grain mashed. This has resulted in large herds numbering anywhere from 500 to 1,300 animals. Beside the slop, additional food is supplied in the nature of roughage and bean meal. This fattening of animals has produced an inferior class of meat rating a lower basic price. Because of market fluctuations, and the possibility of loss through fire and disease, the disposal method is not popular. Pen effluents, even though ponded for pumping to the land, often are washed to the streams, causing a pollution problem.

Farmer stock feeding has certain advantages and also disadvantages. The distilleries are required to erect tanks for dispensing the slop. The price of slop averages about 5 cents per barrel, although some plants make no charge. Necessary supervision of the dispensing station is an expense. However, the method is fairly successful at small plants, as costs to the distillery are low, the farmer

is provided with stock food, and harmful effects on streams are reduced or eliminated, due to the large area of distribution. It is reported that with a balanced diet of 250 pounds of sweet clover to 100 gallons of slop, the production of milk is normal and the quality satisfactory.

BROAD IRRIGATION AND LAGOONING

This method of disposal of grain distillery slop is used only to a limited extent today. It may be used during times of low demand for slop by farmers. The chief disadvantage is due to fly breeding and odor. Pumping is required, and frequent cultivation of irrigated land is necessary. Area of land irrigated approximates one acre for every 10,000 gallons per day of slop.

EVAPORATION

Evaporation of distillery slop affords a sanitary method of disposal and is used in numerous places, particularly at the larger distilleries where costs are reasonable. Costs for the smaller distilleries are excessive and as disposal to farmers is usually moderately successful at such plants, evaporation is seldom used. Several types of evaporators are on the market today, all of which employ multiple effects. The triple effect evaporator in use at distilleries has the advantage over the single effect in that about two and a half times the amount of liquid can be reduced with the same amount of heat. The process of evaporation requires a primary reduction of solids by screens, drag box, and press, with the actual evaporation applied to the thin slop. The products of the evaporator are a thin syrup and a watery condensate. The thin syrup is thoroughly mixed with previously dried grains or with the press cake before entering the drier. The discharged concentrated grain is increased in protein content, with resultant increase in value from $22 to $30 per ton. The condensate from the evaporators containing some volatile solids and polluting properties, is discharged to the sewer. This waste discharge, an analysis of which is shown in table D-6, can be used to advantage in the processing dilutions as it is in a sterile condition.

ANAEROBIC FERMENTATION

The treatment of distillery waste by anaerobic fermentation or digestion has been the subject of study by the Illinois State water survey and the process has been demonstrated on a pilot plant scale. The digested effluent was further treated at the pilot plant on a trickling filter after dilution in the ratio of 1 to 5 with trickling filter effluent. Due to the high nitrates in the filter effluent, this dilution practice was successful in overcoming objectionable odors. The trickling filter was operated at a rate of 250,000 gallons per acre, per day, based on the feed of digester effluent or 1,500,000 gallons per acre, per day, after dilution with trickling filter effluent. A stable effluent was obtained in which dissolved and nitrate oxygen exceeded the biochemical oxygen demand. The process is not in commercial use in the distillery industry.

OTHER TREATMENTS

Other treatments noted in the literature involve many processes, some of which may have promising possibilities. A few will be described briefly.

A recent treatment plant at one of the larger distilleries makes use of a Dorr thickener to treat still slop, in conjunction with quadruple effect Swenson evaporators and Bird centrifuge machine. The thin slop from the thickener goes to the evaporators, and the settled solids to the centrifuge, with the thin waste returning eventually to the thickener. The cake from the centrifuge and sirup from evaporators are mixed and dried. Effluent from evaporators is said to be colorless with a slight grainy taste. Tests on this waste gave methyl orange acidity of 17 parts per million, phenolphthalein acidity of 172 parts per million, pH 3.8, and biochemical oxygen demand 6.5 parts per million. Analysis of final waste composite made at a later date gave phenolphthalein acidity 280 parts per million, pH 3.6, biochemical oxygen demand 59 parts per million, settleable solids, 0, and total solids 60 parts per million.

Reference is made to the treatment of filtrate, produced by heating slop to 240° F. and filtering through cloth. The filtrate may be further treated by a trickling filter or by chlorination and the lactate precipitated with the use of $CaCO_3$.

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Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–5

INDUSTRIAL WASTES (*Not an actual plant*)

River Mileage Index No. *St 20.5*

Type of Plant: *Bourbon Whiskey Distillery.* State: *Kentucky.*
Name of Plant: *Old Bourbon, Inc.*
Municipality: *High Rock.* Main Watershed: *Salt River.*
County: *Moss.* Subwatershed ......
Address: *R. D. White Horse Pike.*
Source of Information: *F. W. Budd, Distiller.*

Plant Operation:
110 hours per week.
144 days annually (Approx. 6 mos.).
80 plant employees including warehouse employees.
6 office employees.

Seasonal Variation: *Probable operation 6 months annually depending upon market conditions, at full capacity.*

(Survey report continued on next page)

Survey by *H. H. Dunn.* Date: *11–20–40.*

Sewered-Population-Equivalent Computation:
Factors used:
B. O. D.: (*1*) *3,500 per 1,000 bushels.*
(*2*) *60 per 1,000 gal.*
Suspended solids: (*1*) *2,260 per 1,000 bushels.*
(*2*) *No record.*
Sewered-population equivalent based on B. O. D.: *15,200.*
Sewered-population equivalent based on suspended solids: *6,800.*
Remarks:
(*1*) *Combined distillery wastes.* (*No intentional slop waste*).
(*2*) *Evaporator condensate waste, totaling 75,000 gallons, in addition to 2,700 gallons tailings.*

Computation by *G. D. R.* Date *12–4–40.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

(*Typical inspection report continuation sheet*)

Old Bourbon, Inc. St–20.5
High Rock, Ky.

Water Supply:

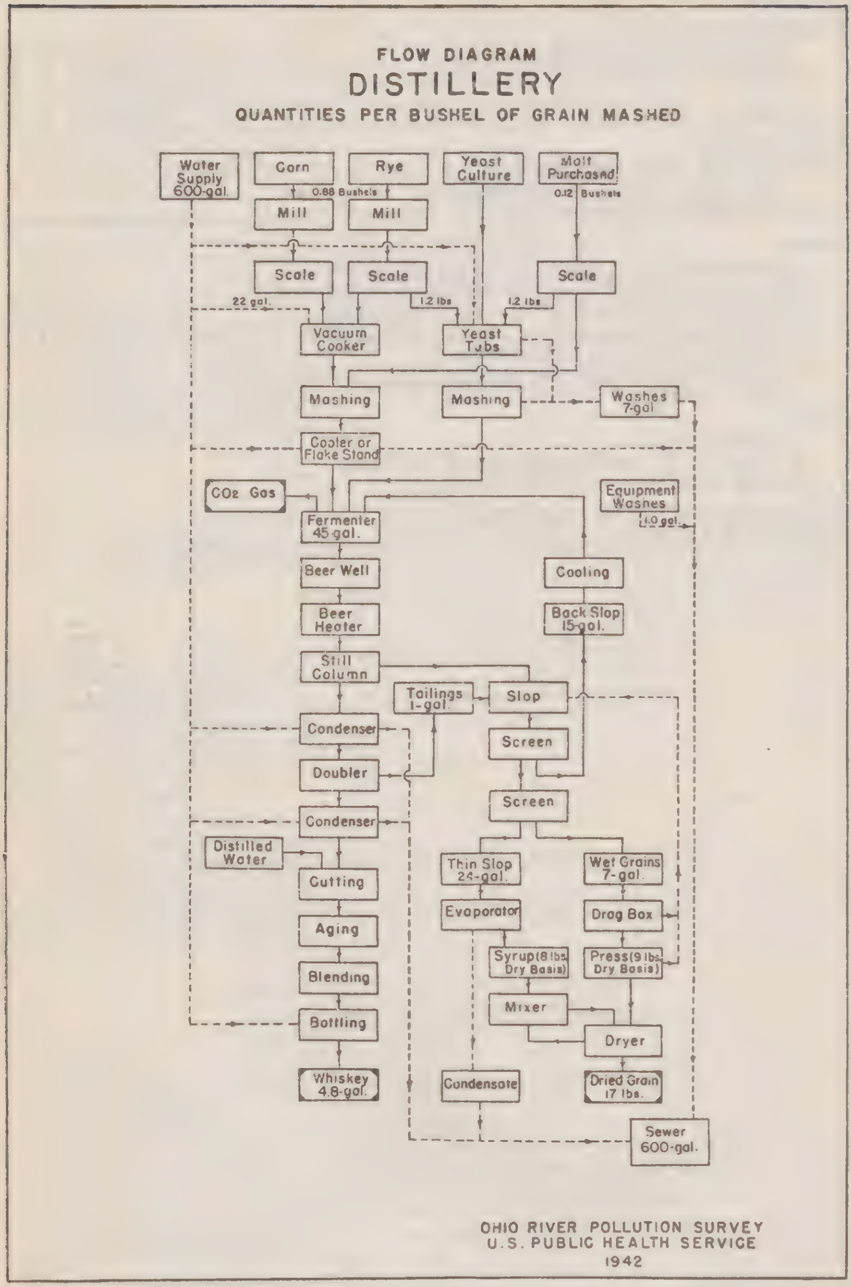
Drinking—City of High Rock	100, 000 G. P. D.
Industrial & Cooling—2 deep wells	1, 100, 000 G. P. D.
Total	1, 200, 000 G. P. D.

Raw Materials:
Corn 70%, Rye 15%, Malt 15%.
Total, 3,000 bushels at full capacity.
Products: Bourbon whiskey, 300 bbls. daily. Yield 4.8 proof gallons per bushel.

Wastes:
1,200,000 G. P. D. based on meter registrations.
Beer slop—135,000 Gals., Screen mesh double O.
Back slop (⅓), 45,000 g., thin slop, 81,000 g.
Treatment: evaporation, mixed with grain. Condensate 75,000 g. p. d. to stream, dried grain 45,000 lbs.
Rectifying still-doubler, tailings 2,700 g. to thin slop.
Spills: Seldom. Analyses: None.

Outlet:
To Salt River.
6″ Circ. V. T. outfalls near top of 10′ bank.
Gaging possible with built-up flume.

Sanitary Sewage: To two septic tanks.
Remarks: Bottling employees will number 75, three days weekly.


FLOW DIAGRAM
DISTILLERY
QUANTITIES PER BUSHEL OF GRAIN MASHED
Water Supply 600-gal.
Corn
Rye
Yeast Culture
Malt Purchased
0.88 Bushels
0.12 Bushels
Mill
Mill
Scale
Scale
Scale
22 gal.
1.2 lbs
1.2 lbs
Vacuum Cooker
Yeast Tubs
Mashing
Mashing
Washes 7-gal
Cooler or Flake Stand
CO2 Gas
Equipment Washes
1.0 gal.
Fermenter 45 gal.
Beer Well
Cooling
Beer Heater
Back Slop 15-gal.
Still Column
Tailings 1-gal.
Slop
Condenser
Screen
Doubler
Screen
Condenser
Distilled Water
Thin Slop 24-gal.
Wet Grains 7-gal.
Cutting
Evaporator
Drag Box
Aging
Syrup (8 lbs. Dry Basis)
Press (9 lbs. Dry Basis)
Blending
Mixer
Bottling
Dryer
Whiskey 4.8-gal.
Condensate
Dried Grain 17 lbs.
Sewer 600-gal.
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

I-5
Rev.12-40

DISTILLERY WASTES (Not an Actual Plant)

Plant Old Bourbon, Inc. State Kentucky Ref.No. St-20.5

City High Rock County Moss Main Watershed Salt River

Address R.D., White Horse Pike Sub-watershed -

Informant F. W. Budd Title Distiller Principal Product Bourbon Whiskey

Plant Operation:	Hours per Week	Days per year	Plant Employees
Average	110	144	80
Maximum			

Seasonal variation Depends upon market conditions

WATER SUPPLY: -	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City	100,000		None
Industrial				
Cooling	Wells	1,100,000		None

RAW MATERIALS:- Corn 2100 bu./day Rye 450 bu./day

Malt 450 bu./day

PRODUCTS:- Alcohol

Whiskey Bourbon, 300 bbls./day - 4.8 proof gals./bu.

Other

WASTES:- Quantity 1.2 M.G.D. How estimated Meter records

Beer Slop - Quantity 135,000 g.p.d. Screen Mesh #00

Back Slop 45,000 g.p.d. Thin Slop 81,000 g.p.d.

Treatment Evaporation, mixed with grain. 75,000 g.p.d. condensate to stream

Dryer 45,000 lbs. dried grain/day Rectifying Still

Tailings 2,000 g.p.d. to thin slop Spills Seldom

Analyses:- Number None Date By whom

Appearance

OUTLET: - Where to Salt River

Description:	Size & shape	Material	Location	Elevation
1.	6" circ.	V.T.	Near top of 10' bank	
2.				
3.				

Gaging possibilities Possible with built up flume

Conditions below outlet: Color

Turbidity Deposits

SANITARY SEWAGE: Disposal 2 septic tanks Persons tributary 75-80

REMARKS

Survey by H.H. Dunn Date 11-20-40

APPENDIX VII OF SUPPLEMENT D

MEAT

An Industrial Waste Guide to the Meat Industry

CONTENTS

LIST OF TABLES

Abstract

The wastes from stockyards, slaughterhouses, and packing houses are similar chemically to domestic sewage but are considerably more concentrated. The principal deleterious effect of these wastes on streams and other bodies of water is their deoxygenating effect.

Stockyard wastes contain animal excreta and the amount and strength of the waste varies considerably, depending upon whether the pens are covered, the presence or absence of catch basins, practice in manure removal, frequency of washing, etc.

Slaughterhouses are establishments for killing and dressing of meat. Relatively little processing of the meat or of byproducts is done. Most slaughterhouses are relatively small although a few in the larger cities may kill several hundred animals per day. Packing houses are equipped to process the meat and byproducts to a much greater extent. The amount of processing varies considerably from plant to plant.

Table Mt-1 shows approximate flows, analyses, and sewered population equivalents for the three types of establishments.

TABLE MT-1.—*Meat industry: Approximate flows, employees analyses, and sewered population equivalents for stockyards, slaughterhouses, and packing houses*

Operation	Unit	Employees per 100 units per day	Waste flow gallons per unit	Typical analysis, parts per million		Sewered population equivalent per unit per day	
				Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids
Stockyard	Acre		25,000	65	175	80	180
Slaughterhouse	Ton on hoof	140	900	2,200	930	100	35
	Hog unit [1]	20	160	2,200	930	18	6
Packing house	Ton on hoof	240	[2] 4,200	900	650	190	120
	Hog unit [1]	30	[2] 550	900	650	24	14

[1] Cattle are 2.5 hog units each. Hogs, calves, and lambs are 1 hog unit each.
[2] Average flow figures at plants on which accurate flow data are available indicate waste flows of 6,000 gallons per ton on the hoof or 760 gallons per hog unit. With higher flows, biochemical oxygen demand and suspended solids concentrations would be lower due to dilution by the greater quantity of water used.

Meat-plant wastes are amenable to biological treatment in plants of the types in common use for treating domestic sewage. Trickling filters, particularly of the type developed by Levine and associates, have proven quite successful. Activated sludge also has been used with considerable success. A number of municipal plants treat large amounts of packing house wastes with domestic sewage. Notable among these are Chicago, where the activated sludge process is used and Sioux Falls, S. Dak., where trickling filters and activated sludge are used. Chemical precipitation is used at a number of packing plants and slaughterhouses where less highly purified effluents are required.

DESCRIPTION OF PROCESS

SLAUGHTERHOUSE

The slaughterhouse or abattoir is principally a killing and dressing establishment, doing little processing of byproducts.

Plants vary in size from the local concerns killing a few animals per week to firms killing several hundred animals daily. Most slaughterhouses in the Ohio Basin are quite small, employing less than 5 to 10 workers.

The process consists briefly of sticking and bleeding animals on the killing floor, cattle being stunned prior to sticking. Hides, skins, and pelts are removed from cattle, calves, and sheep. Hair is removed from hogs by scraping after immersion of the carcass in scalding water. Insides are removed, some of which—livers, hearts, kidneys, etc.—are sent to cooling rooms to be later sold fresh as such. Carcasses are trimmed, washed, dried, and hung in cooling rooms. Hides are salted and stacked until shipped to tanners or wool processing plants. Various offal are segregated for collection and processing by specialty houses such as rendering plants, glue and gelatin works, sausage manufacturers, etc. Many slaughterhouses are now equipped to do rendering—usually for inedible greases and fertilizer tankages. The finished product of the slaughterhouse is the fresh carcass and a few fresh meat byproducts such as hearts, livers, tongue, etc.

PACKING HOUSE

Packing-house killing-floor operations are, in general, carried out with more attention to recovery of salable products. Blood is usually collected, coagulated, and dried for edible and inedible uses. Paunch manure is generally recovered for fertilizer uses. Carcasses are trimmed, cleaned, and cooled much the same as in the slaughterhouse with the exception that the packing house further processes some of the meat by cooking, curing, smoking, and pickling. The packing house is also equipped to process, to varying degrees, the "byproducts" which a slaughterhouse ships out as raw byproduct. Possible exceptions include tanning, wool pulling, manufacture of glues, soaps and fertilizers which are, in general, carried on by independent plants or subsidiaries under another roof. Some of the operations, in addition to those concerning processing of meat cuts, are: Complete rendering of all edible and inedible materials, cleaning casings and making sausage, cleaning and drying hog hair, and canning.

Raw Materials and Product

The average weights of animals slaughtered in the United States, according to the 1937 Census Bureau statistics, are as follows:

Animal	Weight on hoof	Dressed weight[1]
	Pounds	*Pounds*
Cattle	884	459
Calves	188	114
Hogs	218	158
Sheep, lambs	85	40

[1] Not including edible organs.

At plants surveyed in connection with the Ohio River Pollution Survey, the average live weights were approximately 10 percent lower than the above figures. Approximate yields of total meat products and byproducts are as follows:

Classification	Percentage of live weight			
	Beef	Veal	Pork	Lamb
Edible	60.1	58.9	75.8	53.9
Inedible	10.3	10.1	3.7	17.6
Shrinkage [1]	29.6	31.0	20.5	28.5
Total	100.0	100.0	100.0	100.0

[1] Evaporation and valueless material.

The chief product, the carcass, is marketed in various cuts of fresh, smoked, cured, pickled, and canned meats, the slaughterhouse confining its production to fresh meats while the packer produces the full line of processed meats.

The byproducts of the slaughterhouse generally consist of cured hides, skins, and pelts, inedible tallows, fertilizer tankages, miscellaneous fresh offal (collected by specialty houses), pen and paunch manures shipped or carted off for fertilizer.

Packing house byproducts are very numerous. Some of the principal byproducts are as follows (products or uses shown in parentheses are not necessarily processed at the packing house):

(*a*) Hides, skins, pelts (pulled wool).
(*b*) Bone and bone products:
  Edible tallows (lard substitutes).
  Inedible tallows (soap, candles, lubricating oils).
  Glue stocks (glue).
  Bone meal (fertilizers, bone filter charcoals, case-hardening bone).
  Manufacturing stock (buttons, handles, etc.).
(*c*) Horns: (ornaments, combs).
(*d*) Hoofs:
  Outer portion (buttons, fertilizer).
  Inner portion—neat's-foot oil, stearine (soap, candles, glue, fertilizer).
(*e*) Bristles, hair (brushes, upholstering).
(*f*) Intestines:
  Sausage casings.
  Tennis and musical strings, surgical ligatures.
  Ox gall (setting dyes, used in dyes, paints, laundries, and dry cleaning).
(*g*) Fats:
  Oleomargarine.
  Stearic acid.
  (Lubricants, ointments, leather oils.)
  Soap stocks (soaps, glycerine).
(*h*) Meat scrap and blood:
  Meat meal and blood meal stock feeds.
  Tankage (fertilizer or feeds).
(*i*) Glands (medicinal preparations).

Employee: Raw material ratio

Number of plants considered	Plant	Type kill	Employees per 100		
			Head per day	Tons per day	Hog units per day
23 plants	Slaughterhouse	Mixed	31	140	19
7 plants	Packing house	do	37	236	28
7 plants	do	Hogs [1]	37	323	37
1 plant	do	Sheep [2]	5	71	4

[1] 90 percent or more of total kill by number.
[2] 88 percent of total kill by number.

Sources and Quantity of Wastes

SOURCES OF WASTE

Practically every operation connected with this industry is a source of waste through discharge or spills of process liquids and wash waters.

The chief sources of waste are as follows:

- Stockyards.
- Slaughterhouse:
  - Killing floor.
  - Carcass dressing.
  - Rendering.
  - Hide cellar.
  - Cooling room.
- Packing house:
  - Killing floor.
  - Carcass dressing.
  - Rendering.
  - Hide cellar.
  - Hog hair removal and processing.
  - Casing cleaning.
  - Tripe room.
  - Laundry.
  - Glue, soap, fertilizer.

QUANTITY OF WASTE

No information has been found to furnish a complete breakdown of the volumes of waste from the component operations of the slaughterhouse or the packing house, hence the volumes considered hereunder are total combined raw wastes.

Stockyards.—The volume of waste from a 27-acre section of the Chicago stockyards for a 12-hour day flow was 0.623 million gallons or 23,070 gallons per acre per 12-hour day.

Slaughterhouses.—Volumes of waste are small as compared with those of packing houses since the uses of water are relatively few and largely carcass washing and general clean-up washes. Unit volumes of slaughterhouse wastes are as follows:

Number of plants	Process	Volume of waste—gallons per—		
		Animal	Tons on hoof	Hog unit
3 plants	General slaughter	359	867	156
6 plants	Cattle slaughter	395		157
2 plants	Hog killing	143		143

Packing house.—Combined waste volumes are as follows:

Number of plants	Type of kill	Determination	24-hour volume—gallons per—		
			Animal	Ton on hoof	Hog unit [1]
11 plants	Mixed	Maximum	1,470	6,724	981
		Minimum	393	2,788	345
		Average	906	6,053	757
2 plants	Cattle	Maximum	3,091	6,240	1,235
		Minimum	1,286	2,570	514
		Average	2,189	4,405	875
3 plants	Hogs	Maximum	676	5,520	676
		Minimum	488	4,080	488
		Average	552	4,697	552
1 plant [2]	Mixed		2,040	6,850	1,080

[1] Explanation given under Sewered Population Equivalents.
[2] Segregated for consideration as a plant discharging paunch manure to sewer—this plant is also shown separately in the population equivalent tables.

CHARACTER OF WASTES

STOCKYARDS

Stockyards appurtenant to these plants are ordinarily provided with catch basins and are usually floored and sometimes covered.

Wastes consist of liquid excreta and pen wash waters which contain manure.

Uncovered pens are subject to flushing in rainy weather with consequent leachings from manure and carrying over of manure itself to the sewer.

The character of these wastes would be expected to vary widely, dependent on presence or absence of catch basins, practice in manure removal, frequency of washing, etc.

An analysis of the wastes from a Chicago stockyard is as follows:

Determination	Concentration (parts per million)
Total suspension solids	173
Volatile suspension solids	132
Organic nitrogen	11
Amonia nitrogen	8
5-day biochemical oxygen demand	64

SLAUGHTERHOUSE

Killing floor.—Blood is not saved in the smallest establishments and is drained to the sewer or catch basin. Larger houses collect, cook, and press blood for sale to fertilizer manufacturers. It adds a high oxygen demand and color to the waste and the coagulated clots and particles contribute substantially to the suspended solids and general unsightliness of the waste.

Paunch manure is usually segregated from the liquid wastes and disposed of separately. At many of the rural plants it is hauled away by farmers for fertilizer or hog feed. It is frequently sold to rendering plants. A number of the city slaughterhouses dispose of paunch manure with garbage. Others incinerate it. In any case, spills and carelessness allow considerable amounts to enter the sewer. About one-fifth of the slaughterhouses in the Ohio Basin discharge all paunch manure to the sewers.

Floor washes contain blood, manure, flesh, and fat particles.

Carcass dressing.—Carcass washes contain blood, flesh, and fat particles from trimming.

Rendering.—Many slaughterhouses render offal for inedible tallows and fertilizer tankage. Where wet rendering is practiced a tank water remaining after grease and residue are taken off must be disposed of. Larger houses evaporate this tank water to produce a sticky residue (called stick) which is mixed with the fertilizer tankage. In some houses this tank water is wasted to the sewer with its consequent load of high biochemical oxygen demand and solids content.

Where dry rendering is done the principal waste comes not from the tank—since no water is used and the entrained water evaporates—but from the draining of the hashed offal; it consists of small flesh and fat particles and intestinal contents. The pressing of the residue into cakes produces a press liquor which is ordinarily put back into the rendering vat with the next batch—this liquor is largely grease.

Wash waters, both floor and equipment, from tank rooms contribute varying amounts of pollutional material, depending on the care exercised in handling materials and on general cleanliness.

Hide cellar.—Green hides are chuted to the cellar from the killing floor. Here they are piled flesh side up and sprinkled with salt. A small amount of drainage from these piles, in addition to floor wash, goes to the sewer.

Hog hair removal.—Hair is loosened in a scalding tub or vat and removed by scraping. Discharge of vat waters and scrapings contribute hair, dirt, and scurf from the hog skin.

Cooling room.—Drippings from carcasses, mostly blood, are contained in the floor washes. Some houses may use sawdust on the floor which is swept up periodically. Subsequent floor washes carry a large amount of suspended material.

Some average analyses representative of combined slaughterhouse wastes are as follows:

Type kill	Concentration (parts per million)				
	Solids			Total nitrogen	5-day biochemical oxygen demand
	Total	Volatile	Suspended		
General	4,586	2,324	929	324	2,240
Cattle	4,099	2,049	820	154	996
Hogs	3,587	1,795	717	122	1,048

PACKING HOUSE

Killing floor.—Blood is usually collected, coagulated by heating, and filtered. In some cases the filter liquid effluent is cooked in steam coil equipped vats; after cooking the liquid is pumped into the stick stock and evaporated and the solids added to the blood for disposal as blood fertilizer. In some plants, however, this liquor may be discharged as waste. Many of the smaller plants make no attempt to recover blood.

Paunch manure is sometimes rendered for inedible greases or sold for fertilizer. The commonest method of disposal in the Ohio Basin is to farmers or by dumping on land. About one-third of the packing houses in the Ohio Basin, including some of the largest ones, discharge paunch manure to the sewers.

Carcass dressing.—This operation is, in general, no different than that carried on in the slaughterhouse, wash wastes being discharged.

Rendering.—The larger packing houses do both edible and inedible rendering and make use of various rendering processes which include high and low temperature dry rendering from which, as mentioned under slaughterhouses, the wastes discharged come from the washing and draining of hashed ingredients, and steam rendering which produces a tank liquor containing gelatin and various nitrogenous extractives. This liquor may be discharged to the sewer or it may be evaporated to stick and mixed with stock feed or fertilizer, depending on the materials rendered. Hot water rendering of shinbones and feet of cattle to produce neatsfoot oil stock produces tank liquors of pollutional nature.

Press liquors from the tank residues are discharged to the sewer. In some cases these liquors have a high grease content.

Hide cellar.—The wastes are similar to those from a slaughterhouse.

Hog hair removal.—In the larger plants hair removal is accomplished by a mechanical scraper. The hair is removed, washed, and sold green, or further

processed by soaking for 24 hours and steam boiling for 8 to 10 hours with a small amount of caustic soda. The hair is removed, steam cleaned and dried. The scalding vat, tank, and wash waters, containing dirt, scurf, and escaped hair is discharged. Most of the smaller packing plants do not recover hair.

Casing cleaning.—Casings are washed, cleaned of their contents by squeezing or pressing by hand or machine, salted, drained, resalted, and packed for shipment. Trimmings and cleanings are capable of rendering for grease extraction. The wash waters are discharged.

Tripe room.—The tripe or muscular part of the stomach of cattle is washed, scalded, scraped, and boiled, after which fatty layers are scraped off and the tripe pickled in vinegar. Wash, scalding, and cooking waters containing grease and suspended matter, and spent pickle liquors are discharged.

Sausage room.—Process consists of preparing fillings from meat, and stuffing the casings. Utensil and floor washes are discharged. Much small offal is reported to reach the sewer from the sausage room of the small factory.

Laundry.—The laundries of the large plants are of considerable size. An analysis of this waste is included with the tabulation of analyses of hog plant wastes.

Glue stocks.—The manufacture of glue is usually carried out in a separate plant. However, a gelatin may be produced at the packing house for sale to glue works as a raw material. This gelatin is produced by extracting the gelatinous matter by rendering of heads, feet, snouts, bones, ears, tendons, hide trimmings, etc. The wastes discharged consist of wash and steep waters prior to rendering.

Soap.—The manufacture of soaps as such is confined to some of the largest houses. The average packing house produces the inedible greases sold to the soap manufacturers. The wastes produced from the manufacture of such greases is covered under rendering.

Fertilizers.—The production of fertilizers as such has lost some of its importance in the packing house with the advent of dry rendering which enables production of higher grade tankages which are used more for stock feed, than for fertilizer. The fertilizer industry, once largely a packing-house operation, has become more the province of the chemical industry, and packing-house fertilizer stocks are shipped for use by fertilizer plants.

The character of the major components of the waste of a hog packing house is indicated in table Mt–2.

TABLE MT-2.—*Analyses of major components of waste from hog packing house* [1]

	Concentration (parts per million)							
	Solids		Nitrogen		Cl as NaCl	Oxygen consumed	5-day Biochemical oxygen demand	pH
	Total	Suspended	Organic	NH_3				
Killing department	1,840	220	134	6	435	500	825	6.6
Blood and tank water	44,640	3,690	5,400	205	6,670	----------	32,000	9.0
Scalding tub	13,560	8,360	1,290	40	640	4,300	4,600	9.0
Hog dehairing	1,540	560	158	10	290	620	650	6.7
Hair cook water	4,680	80	586	30	290	----------	3,400	------
Hair wash water	7,680	6,780	822	18	230	1,680	2,200	6.9
Meat cutting	2,840	610	33	2.5	1,620	260	520	7.4
Gut washer	22,600	15,120	643	43	360	----------	13,200	6.0
Curing room	26,480	1,800	83	12	19,700	2,520	2,040	7.3
Curing room showers	34,100	1,720	255	25	29,600	875	460	6.7
Cured meat wash	9,560	920	109	17.5	6,200	950	1,960	7.3
Pickle	140,000	----------	2,750	37	77,800	----------	18,000	5.6
Sausage and miscellaneous	11,380	560	136	4	880	460	800	7.3
Lard department	820	180	84	25	230	200	180	7.3
Byproducts	4,000	1,380	186	50	1,330	970	2,200	6.7
Laundry	18,620	4,120	56	5	--------	780	1,300	9.6

[1] Iowa Engineering Experiment Station Bulletin No. 130.

Analyses of the combined raw wastes from packing houses are shown in table Mt–3. Most of these plants are in Chicago.

TABLE MT-3.—*Analyses of combined packing house wastes*

Number of plants	Concentration (parts per million)				
	Suspended solids		Nitrogen		5-day biochemical oxygen demand
	Total	Volatile	Organic	NH_3	
28 plants	699	597	116	25	953
4 plants	398		98		587
1 plant	467		68		550
1 plant	708	613			758
1 plant	720				955
1 plant	233	195			372
1 plant	534	449	71	12	1,240
1 plant	665	658	167	14	1,634
Average [1]	645	582	113	24	909

[1] Average weighted by plants.

Sewered population equivalents.—Table Mt-4 shows approximate sewered population equivalents on the basis of biochemical oxygen demand and suspended solids for stockyards, slaughterhouses, and packing houses. These are based on a per capita discharge of 0.167 pound of 5-day biochemical oxygen demand and 0.2 pound of suspended solids per day. Analyses indicate that the wastes from hog packing are greater per pound of animal than those from cattle packing. The method of evaluating the wastes from a mixed kill in terms of hog units assumes that the waste per head of cattle is equivalent to that from 2.5 hogs, while calves and lambs are each equivalent to a hog. These factors were suggested by Milling and Poole. Other authorities have used other factors. The sewered population equivalents shown on the basis of live weight are somewhat more reliable for use when an appreciable portion of the pack is cattle. When the kill is primarily hogs, the hog unit basis is better. The wide variations in the sewered population equivalents per animal or per ton from various plants makes differentiation between mixed packing, cattle packing, and hog packing an unwarranted refinement.

TABLE MT-4.—*Meat industry; Summary of sewered population equivalents*

Type of plant	Sewered population equivalent					
	Per acre		Per ton on hoof per day		Per hog unit per day	
	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids
Stockyard	80	180				
Slaughterhouse			100	35	18	6
Packing house			190	120	24	14

POLLUTION EFFECTS

Meat-plant wastes are quite similar to domestic sewage in their composition and in their effects upon receiving bodies of water. The danger from pathogenic organisms in packing house or slaughterhouse wastes, however, is slight. Oxygen depletion, sludge deposits, discoloration, and general nuisance conditions are the principal deleterious effects of meat-plant wastes.

REMEDIAL MEASURES

PLANT PRACTICES

Various plant practices in more or less common use tend to reduce the quantity or strength of wastes from meat plants. Most of these practices are profitable, at least in the larger plants. Among them are blood recovery, utilization of paunch manure, grease recovery, utilization of tank waters and tankage press liquors, etc. The extent to which such practices are employed affects greatly the pollution load from the plant. Baffled basins or traps on waste lines are in

common use for grease recovery but the efficiency of the units varies considerably. Many grease traps are inadequate in size and receive little attention. Blood recovery practices also vary widely. Some plants recover none of the blood, some recover only the first blood, while at other plants relatively little blood enters the sewers. In most plants where paunch manure is recovered a certain amount of the waste reaches the sewers.

No data are available as to the possible reduction in waste load that can be effected by recovery of byproducts, careful segregation of solid wastes, and generally good housekeeping methods but the reduction must be considerable.

TREATMENT

Chicago experiments.—The most extensive studies of treatment for meat-plant wastes were made by the Sanitary District of Chicago through the operation of the Packingtown testing station from 1912 to 1914 and from 1915 to 1918. Other extensive studies of such wastes have been made by Levine and his associates, Halvorson, and others. All of the standard methods of waste treatment have been investigated and a number of special methods have been developed. Both trickling filters and activated sludge have been found suitable for treatment of meat-plant wastes and chemical precipitation is used in a number of plants where lower reductions in biochemical oxygen demand are sufficient.

The following is abstracted from a summary of the Packingtown studies by Mohlman.

Treatment processes studied included fine screening, sedimentation, chemical precipitation, trickling filters, and activated sludge.

The results of these extensive studies are as follows:

Screening by rotary wire mesh screen removes coarse materials such as hair, flesh, paunch manure, and floating solids. Frequent clogging of screens necessitated washing with hot water and soda ash. Removals of 9 percent suspended solids on 20-mesh screen and 19 percent on 30-mesh screen were reported. There was no appreciable biochemical oxygen demand reduction.

Sedimentation, in an Imhoff tank, was found the most satisfactory process for clarification. Chemical precipitation, while removing more suspended solids, produced an excessive volume of sludge which was ill-smelling and hard to dry. Imhoff removals were approximately 65 percent suspended solids, 35 percent biochemical oxygen demand with detention periods of 1 to 3 hours, with a sludge containing 90-percent moisture.

Filtration on trickling filters consisting of 5½ feet of 1¼- to 2-inch stone over 6 inches of 2- to 4-inch stone, at rates varying from 0.6 to 1.0 m. g. a. d., gave satisfactory nitrified effluents which could be well clarified by secondary sedimentation. The filters were reported to give little trouble from pooling, flies, or odors; they unloaded continuously. Removals were 81 percent biochemical oxygen demand (88 percent over-all).

Activated sludge gave a satisfactory effluent with 9 hours aeration and 3.5 cubic feet air per gallon. Nitrates ran 5 to 7 parts per million in summer but in winter it was necessary to incease air rates up to 4 or 5 cubic feet per gallon and even at this high rate nitrates were not produced. The suspended solids and biochemical oxygen demand removals were higher than those of the settled trickling filter effluents.

Table Mt-5 shows typical and representative analyses of the applied raw waste and the effluents produced follows:

TABLE MT-5.—*Packingtown testing station (Chicago); Results of various treatment processes*

Determination	Effluent (parts per million)				
	Raw waste	Screen	Imhoff tank	Trickling filter	Activated sludge
Ammonia nitrogen	22.0	22.0	29.0	16.0	10
Organic nitrogen	79.0	75.0	60.0	20.0	10
Nitrite nitrogen	.5	.5	.2	2.2	1
Nitrate nitrogen	3.0	3.0	1.7	16.4	5
Oxygen consumed	268.0	240.0	180.0	50.0	
Chlorine	1,000.0	1,100.0	1,100.0	1,100.0	1,100
Alkalinity	212.0	212.0	240.0	200.0	
Suspended solids	605.0	515.0	210.0	75.0	30
Biochemical oxygen demand (10-day)	990.0	930.0	630.0	120.0	50

Double filtration.—The studies by Levine and his associates at Mason City, Iowa, led to the construction in 1929, of a plant providing double filtration to replace an activated sludge plant which had failed due to a greatly increased load and wide fluctuations in the strength and character of the wastes. The plant provides primary clarification with 2 hours' detention, primary filtration at a rate of 3,000,000 gallons per acre per day, on a washable filter 4 feet deep with ½- to 1-inch dolomite filter media, intermediate clarification with 2 hours' detention, secondary filtration at a rate of 1,500,000 gallons per acre per day on an 8-foot deep filter with 1- to 3-inch dolomite filter media, and final sedimentation. Table Mt–6 shows the results of treatment during 1933. The average volume treated was about 600,000 gallons per day as compared with a design flow of 750,000 gallons per day.

TABLE MT–6.—*Purification of packing-house waste at Mason City, Iowa, for the year 1933*

	Raw waste	Primary clarifier effluent	Intermediate clarifier effluent	Final clarifier effluent
	Parts per million	*Parts per million*	*Parts per million*	*Parts per million*
Organic nitrogen	150.4	97.9	54.3	12
NH_3	46.5	63.0	81.3	35
Biochemical oxygen demand	1,437 (±402)	1,020 (±253)	534 (±232)	82 (±81)
Number of samples for biochemical oxygen demand	201	197	198	202
	Over-all percent reduction			
Organic nitrogen		34.7	63.8	92.0
NH_3				24.7
Biochemical oxygen demand		29.0	62.8	94.3

A plant similar to the Mason City plant has been installed by the Armour Packing Co. at West Fargo, N. Dak. The following data are taken from a description of the plant by Howson. The treatment process includes the following steps: (1) Fine screens, (2) grit removal, (3) grease flotation, (4) flocculation, (5) primary settling, (6) washable primary trickling filters, (7) secondary settling, (8) final trickling filters with two units which may be operated in series or in parallel, (9) final settling, and (10) discharge to river over aerating cascades. Although essentially like the Mason City plant, the West Fargo installation includes a number of improvements and changes which have been found desirable as a result of the experience with the earlier plant.

The grit chamber and settling tank each provide 30 minutes' detention and together remove about 90 percent of the settleable solids and 35 to 40 percent of the biochemical oxygen demand. The grease flotation tank provides 15 minutes' detention and is divided into aeration and coalescing compartments by an inclined baffle. The flocculation compartment provides 40 minutes' detention and is equipped with 3 paddle-type flocculators in series. Flocculation without the addition of chemicals increases the biochemical oxygen demand removal through the tanks by about 5 percent. In order to equalize the flow through the secondary devices, a storage tank with a capacity of 20 percent of the day's flow is provided. The primary filters are 6 feet deep and are equipped with both air and water wash systems. The filter media is 1- to 2-inch granite and the operating rate is about 6,000,000 gallons per acre per day. Used wash water flows to a storage tank from which, after settling, the water flows to the secondary clarifier and through the rest of the plant. The filters are washed every 2 or 3 weeks. In the intervening period the wash water settling tank is used for sludge thickening. The primary filters, together with the primary and secondary clarifier, have consistently reduced the biochemical oxygen demand of the raw wastes from 1,000 parts per million to 250–350 parts per million when loaded at rates of 5,000 to 6,000 pounds of biochemical oxygen demand per day. Secondary settling is in a Dorr clarifier with a detention period of 1 hour. The final filters are conventional trickling filters 6 feet deep and dosed at a rate of about 1,400,000 gallons per acre per day when operated in parallel. The final filters are ordinarily operated in parallel. Over-all reductions of more than 95 percent of the biochemical oxygen de mand have been accomplished consistently.

Several additional plants providing high rate washable filters have recently been constructed at packing houses at South St. Paul, Minn. These plants do not have final filtration.

High rate filtration.—The Hormel plant at Austin, Minn., has abandoned its chlorine precipitation plant, built in 1931, in favor of high-rate filtration of the type developed by Halvorson.

Activated sludge.—Results of tests by the Indiana State Board of Health on the activated sludge treatment plant of the Kuhner Packing Co., Muncie, Ind., in 1937 and 1938 have been reported in a paper by Milling and Poole, from which the following is extracted.

The plant cost $41,000, has a design capacity of 200,000 to 500,000 gallons per day estimated to treat the process wastes resulting from packing operations of 350 to 500 hog units per day. This plant has several unique features including pre-aeration of incoming wastes, intermittent intensity of aeration in the main aeration units with provisions for occasional aeration in the final settling tank, split flow of return sludge, and intermixing of waste sludge in the pre-aeration tank and primary settling tank.

Raw wastes are aerated 30 to 60 minutes in the presence of activated sludge in a pre-aeration tank. An air lift consisting simply of a hood over two diffuser plates raises the effluent to the primary settling tank. This tank is equipped with straight-line sludge removal apparatus with skimmer. Use is again made of the air lift to raise effluent from weir trough to aeration tanks. The spiral flow aeration tanks, two in number, each having two channels 48 by 22.5 feet and 10 feet deep, can be operated in series up to full four passes. Final clarification is provided by a center inlet, radial-flow settling tank equipped with rotary continuous sludge-removal apparatus. An air lift removes the sludge to the pre-aeration and aeration tanks. At the time of the tests (1937 and 1938) sludge was pumped from primary tank by displacement pump or air lift directly to the old sand beds. It was expected that a digestion tank would be provided in the near future. Compressors, pump, control equipment, laboratory and office are housed in a brick building.

In times of abrupt changes in loading and temperature, bulking occurred in the final tank. To prevent discharge of sludge and relieve the condition the final tank was lowered several inches by shutting off the influent and applying air to the final tank for 10 minutes every 2 hours.

About 90 percent of the return sludge is passed to the aeration tanks and 10 percent to the pre-aeration tanks. No mention was made of aeration tank foaming.

Results of operation during the sampling periods are shown by the following table. The wastes ordinarily result from packing operations with a mixed kill of cattle, hogs, calves, and lambs. At the time of the tests the kill was cattle and hogs.

TABLE MT–7.—*Results of activated sludge treatment of packing house wastes at Muncie, Ind.*

Sample	Raw waste (parts per million)		Reductions in percent			
			By primary clarifier		Over-all	
	Suspended solids	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand
9-hour composite	1,016	940	58	29	98.7	99.5
24-hour composite		980				98.3
Do	400	353	80.5	49	98.6	98.4
Average	708	758	51.6	44	97.5	98.8

About 4.25 cubic feet of air was used per gallon of waste treated and about 780 cubic feet of air per pound of biochemical oxygen demand reduction. The biochemical oxygen demand of the raw waste averaged 1,187 pounds per day or about 3.14 pounds per hog unit. The cost of operation based on the first 6 months operation including two operators, power, maintenance, interest and depreciation was estimated at $21.93 per day or 5.5 cents per hog unit on the basis of 400 hog units per day.

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Chemical precipitation.—A number of precipitants have been used in various plants treating packing house wastes. The use of superchlorination for the precipitation of proteins as practiced at Austin, Minn., has been abandoned because of cost, the toxicity of the sludge, and the necessity of excluding much of the waste from the treatment process.

At Phoenix, Ariz., a packing plant uses ferric chloride made from wire and chlorine. Biochemical oxygen demand reductions from 1,448 to 188 parts per million and suspended solids reductions from 2,975 to 167 parts per million are obtained, using 1,000 pounds of wire and 1,150 pounds of chlorine per million gallons. Operating costs are $68 per million gallons but the effluent is sold for irrigation, grease recovered, and sludge gas utilized and the net cost is said to be about $25 per million gallons.

At Madison, Wis., two-stage chemical precipitation, using zinc chloride and alum followed by settling, lime treatment and secondary settling has proved successful. Grease is recovered; the sludge dewatered on a vacuum filter and used for fertilizer. The effluent is clear and straw colored. Biochemical oxygen demand reductions from about 1,600 to 200 parts per million and suspended solids reductions from about 1,200 to 80 parts per million are reported. This process was developed by Domogall and is patented.

Eldridge has found fill and draw chemical precipitation, using chlorine and ferric chloride, well suited to the needs of small slaughterhouses. He suggests segregation of all unpolluted water, recovery of as much blood, paunch manure, etc. as possible prior to treatment. The coagulation and settling tank should be large enough to hold 1 day's flow and should be equipped with a stirring mechanism. Chlorine gas should be applied through diffusers, the flow of chlorine being regulated by a needle valve in the chlorine feed line. About one-eighth of a gallon of 40 percent ferric chloride is used per 1,000 gallons of waste. The sludge is sterile and can be dried on sand beds or disposed of on land. Such a plant constructed at the Grand Rapids Packing Co., to treat 5,000 gallons of waste per day cost $500, exclusive of housing, and operating charges were $1.50 per day. The biochemical oxygen demand was reduced from 2,700 to 310 parts per million and the suspended solids from 1,320 to 178 parts per million. The principal disadvantage of this type of treatment is the danger of using chlorine without relatively expensive chlorine control machines.

Treatment with municipal sewage.—Since meat plants are concentrated in the larger cities, the commonest method of treating their wastes is in municipal treatment plants. Chicago is the largest center of meat packing in the world and the wastes from these establishments are being treated successfully by the activated sludge process. Other cities treat varying amounts of meat plant wastes by plain sedimentation, chemical precipitation, trickling filters, activated sludge, and combinations of these methods. Pretreatment of the packing house waste prior to admission to the city sewers is required in a number of places. Screening and clarification are the most common methods of pretreatment but in a few instances more complete treatment such as chemical precipitation, grease removal, or chlorination is required.

At Sioux Falls, S. Dak., where packing house wastes are about 76 percent of the total waste load, a municipal treatment plant including chemical precipitation trickling filters, and activated sludge has been successful in producing a highly purified effluent. Experiences in treating these wastes have been described by Bradstad and Bradney. The following data are abstracted from their article. An earlier trickling filter plant operated satisfactorily with over-all removals of 80 to 85 percent of the biochemical oxygen demand and suspended solids but the residual biochemical oxygen demand polluted the receiving stream seriously. After considerable experimental work, the plant was remodeled to provide chemical precipitation of the packing house wastes, separate sedimentation of the domestic sewage, followed by trickling filters, activated sludge treatment (about 5 hours aeration), and final sedimentation. Considerable difficulty with floating sludge in the final tanks was experienced due to denitrification of the effluent. This was controlled by regulating the dissolved oxygen content in the aerator within the narrow range which would prevent both floating sludge and bulking. In order to do this effectively it was necessary to overcome the wide fluctuations in flow to the aerator. This was done by regulating the rate of pumping from the filter to the aerator and, although the filter effluent backed up in the filter gallery, this had no detrimental effect on the efficiency of the units. The following table shows the average results during a 7-month period (March–September 1937) when the wastes were separately clarified, filtered at 4.0 m. g. a. d. during the day and 2.0 m. g. a. d. at night, aerated, and settled. No chemicals were used in the flocculation.

TABLE MT–8.—*Results of treatment of packing house waste and domestic sewage at Sioux Falls, S. Dak.* (*March–September 1937*)

	Suspended solids		5-day biochemical oxygen demand	
	Parts per million	Percent removal (over-all)	Parts per million	Percent removal (over-all)
Packing house, raw [1]	720		955	
Domestic, raw	403		325	
Combined, raw	532		575	
Packing house primary effluent	321	55.4	568	40.5
Domestic primary effluent	120	70.2	149	54.2
Combined primary effluent	209	60.7	322	44.0
Trickling filter effluent	200	62.4	187	67.5
Final effluent	9.9	98.1	10.6	98.2

[1] Packing house waste screened and settled briefly before discharge to municipal sewers.

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TYPICAL INSPECTION REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–7

(*Not an actual packing house*)

INDUSTRIAL WASTES

River Mileage Index No. *K 127*

Type of Plant: *Packing House.* State: *W. Va.*
Name of Plant: *Abbott-Orr Packing Co.*
Municipality: *Bardell.* Main Watershed: *Kanawha.*
County: *Dosey.* Subwatershed ______.
Address: *864 E. Main St.*
Source of Information: *John Smith, Supt.*
Plant Operation:
300 plant employees, 30 office.
40 hr. per week, 300 days per year.
Seasonal Variation:
June–Oct. 96% of ave.
Oct.–Feb. 110% of ave.
Feb.–June 94% of ave.

(Survey report continued on next page)

Survey by *A. K. Brown.* Date: *7–11–39.*

Sewered Population Equivalent Computation:
Factors used:
B. O. D.:*190.* Suspended solids: *120.*
Sewered population equivalent based on B. O. D.: *25,000.*
Sewered population equivalent based on suspended solids: *16,000.*
Remarks:
Wet rendering. Tankage press liquor to sewer.
P. E. based on 110% of ave. kill.
Computation by *W. Wimple.* Date: *10–14–39.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.

(*Typical inspection form continuation sheet*)

Abbott-Orr Packing Co. K–127
Bardell, W. Va.

Water Supply: 329,000 g. p. d. from city supply for drinking and industrial purposes. No additional treatment. Cooling water from Kanawha River without treatment. Quantity unknown.

Kill:
Average 240,000 lbs. live weight per day.
Number per year:

Beef	26, 000
Calves	62, 000
Lambs	45, 000
Hogs	140, 000

All U. S. inspected. No local inspection.

Wastes: 329,000 g. p. d. plus cooling water (estimated from meter readings on water supply).

Blood recovered, mixed with tankage.

Paunch manure dumped in tanks. Overflow liquor to sewer. Solids shipped. Wet rendering. Liquor to #1 sewer.

Grease trap 35′×10′×3′. Receives wastes from killing floor, casing and sausage department, and tank house.

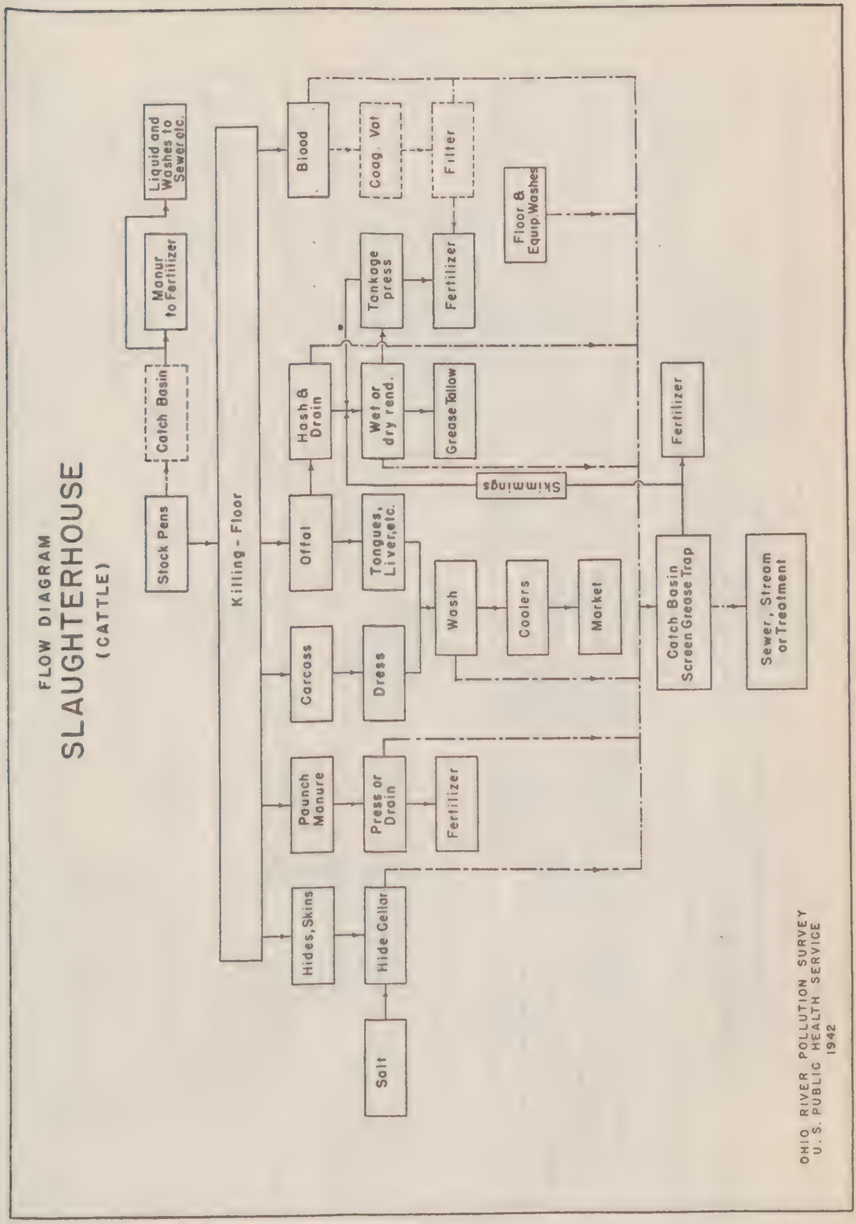
No treatment, no analyses.

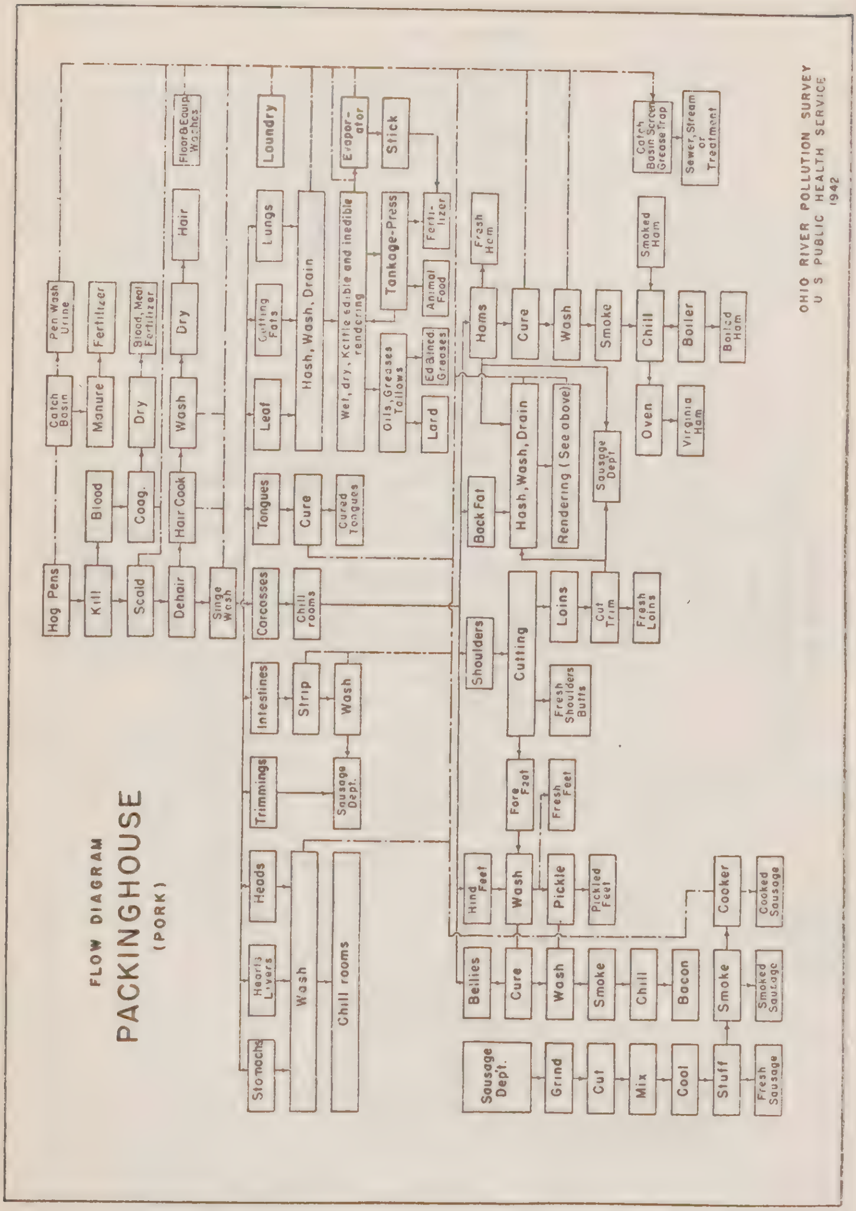
Outlet: Three outlets direct to Kanawha River.
#1—15″ tile—grease trap effluent.
#2—10″ tile—stock pens (catch basin on line).
#3—8″ tile.

Good opportunity for gaging. Outlets are exposed.

Sanitary Sewage: To #3 sewer. 330 persons tributary.

Remarks: Slight red color and some grease noticeable in river below outlets. Storm drainage and cooling water to ditch west of plant. No evaporators, tankage press liquor discharged to #1 sewer.


FLOW DIAGRAM
SLAUGHTERHOUSE
(CATTLE)
Stock Pens
Catch Basin
Manur to Fertilizer
Liquid and Washes to Sewer etc.
Killing - Floor
Blood
Coag. Vat
Filter
Fertilizer
Tankage press
Floor & Equip. Washes
Hash & Drain
Wet or dry rend.
Grease Tallow
Fertilizer
Skimmings
Offal
Tongues, Liver, etc.
Carcass
Dress
Wash
Coolers
Market
Catch Basin Screen Grease Trap
Sewer, Stream or Treatment
Paunch Manure
Press or Drain
Fertilizer
Hides, Skins
Hide Cellar
Salt
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1942


FLOW DIAGRAM
PACKINGHOUSE
(PORK)
Hog Pens
Catch Basin
Pen Wash Urine
Kill
Manure
Fertilizer
Blood
Scald
Coag.
Dry
Blood, Meat Fertilizer
Dehair
Hair Cook
Wash
Dry
Hair
Floor & Equip. Washes
Singe Wash
Carcasses
Tongues
Leaf
Cutting Fats
Lungs
Laundry
Chill rooms
Cure
Cured Tongues
Hash, Wash, Drain
Wet, dry, Kettle edible and inedible rendering
Evaporator
Stick
Oils, Greases Tallows
Tankage-Press
Lard
Edible and Greases
Animal Food
Fertilizer
Intestines
Strip
Wash
Trimmings
Sausage Dept.
Heads
Hearts Livers
Stomachs
Wash
Chill rooms
Shoulders
Cutting
Fresh Shoulders Butts
Back Fat
Hash, Wash, Drain
Rendering (See above)
Loins
Cut Trim
Fresh Loins
Sausage Dept
Hams
Fresh Ham
Cure
Wash
Smoke
Chill
Smoked Ham
Boiler
Boiled Ham
Oven
Virginia Ham
Catch Basin Screen Grease Trap
Sewer, Stream or Treatment
Fore Feet
Fresh Feet
Hind Feet
Wash
Pickle
Pickled Feet
Bellies
Cure
Wash
Smoke
Chill
Bacon
Sausage Dept.
Grind
Cut
Mix
Cool
Stuff
Smoke
Cooker
Fresh Sausage
Smoked Sausage
Cooked Sausage
OHIO RIVER POLLUTION SURVEY
U S PUBLIC HEALTH SERVICE
1942

MEAT INDUSTRY WASTES (Not an Actual Plant)

Plant Abbott - Orr Packing Co. State W. Va. Ref.No. K 127

City Bardell County Posey Main Watershed Kanawha

Address 864 East Main St. Principal Product Meat

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	40	300	300
Maximum			

Seasonal variation June-Oct. 96 %, Oct.-Feb. 110 %, Feb.- June 94% of ave. Killing days per week

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial	City	329,000		None
Cooling	River			

KILL:- Per Year	Beef	Calves	Lambs	Hogs
Normal	240,000 lbs/day - 26,000 lbs.	62,000 lbs./day	45,000 lbs/day	40,000 lbs/day
1938	240,000 lbs/day			
Maximum				

If available, give live weights under remarks.

U. S. Inspected? 100 % Local Inspection? No

WASTES:- Quantity 329,000 g.p.d. + cooling How estimated Meter records

Blood recovered Yes

Method Cooled and mixed with tankage - Liquor discharge to Sewer

Paunch Manure Dumped in tanks - Overflow liquor to sewer - solids shipped

Rendering wet - tank liquors discharged to sewer (No. 1 sewer)

Segregation of Strong Wastes

Difficulties

Grease traps Yes - 35 ft. x 10 ft. - 3 ft. deep - receives killing floor, casing and sausage dept. and tank house wastes

Other treatment None

Analyses: - Number None Date By whom

Appearance Slight red

Stock Pens: Area Stock capacity

OUTLET: - Where to Direct to Kanawha River thru 3 outlets

Description:	Size and shape	Material	Location	Elevation
1.	15" circular	Vit. Tile	Grease trap effluent	
2.	10" "	" "	Pens (catch basin on line)	
3.	8" "	" "		

Gaging possibilities Good - outlets exposed, C. B and Grease trap

Conditions below outlet: Color

Turbidity Slight grease on river Deposits None

SANITARY SEWAGE: Disposal in No. 3 - 8" sewer Persons tributary 330

REMARKS No evaporators, tankage press liquor discharged (No. 1 sewer) cooling water to separate sewer (not listed above)

Survey by A. K. Brown Date July 11 - 1939

APPENDIX VIII OF SUPPLEMENT D

MILK

An Industrial Waste Guide to the Milk Processing Industry

CONTENTS

LIST OF TABLES

Abstract

A plant handling or processing milk and its products may be generally classified as a receiving station, bottling works, cheese factory, creamery, condensery, dry-milk plant, ice-cream plant, or general dairy. The last group consists of combinations of some or all of the other types of plants.

Wastes are made up, for the most part, of various dilutions of whole milk, skim milk, buttermilk, and whey from accidental or intentional spills; drippings allowed to waste by inefficient processing equipment, methods, or operations; washes containing alkali or other chemicals used to remove milk, milk products, and partially caramelized materials from cans, bottles, tanks, vats, utensils, pipes, pumps, hot wells, pans, coils, churns, and floors; and process washes of butter, cheese, casein, and other products.

Fresh wastes may be acid or alkaline. Where receiving waters cannot provide sufficient oxygen for aerobic decomposition, the lactose is converted to lactic acid and the wastes become sufficiently acid to precipitate the casein. The heavy black sludge deposits and strong pigpen odors caused by the putrefying casein characterize milk-waste pollution. Typical analytical results and sewered population equivalents are shown in table Mk–1.

Remedial measures may generally be classified as byproduct recovery and waste treatment. The first group includes the recovery of whole milk by the installation of drip savers; the processing of skim milk, whey, and buttermilk into powder, casein, albumin, or lactose; and conversion of waste products into stock feed.

The chief treatment methods in use today are dilution, irrigation, septic tanks, trickling filters, activated sludge, and the Guggenheim process. Dilution or irrigation are usually sufficient where plants are small and isolated. The use of trickling filters has been found to be the most widely applicable method of treating milk wastes, averaging 80 to 90 percent reduction in 5-day biochemical oxygen demand. Activated sludge has had limited use. Biochemical oxygen demand removals by this process average 90 percent or more but close supervision and control are required. One of the newest developments is the Mallory process, utilizing activation followed by aeration. The treatment units are prefabricated and easily set up where needed. Data available indicate a high efficiency, based on biochemical oxygen demand removals. The Guggenheim process, combining chemical precipitation and aeration, is finding limited application, chiefly at cheese plants. Care must be taken to exclude whey since the process is upset by even small amounts. High efficiencies can be obtained under very strict control and supervision.

TABLE MK–1.—*Typical analytical results and sewered-population equivalents*

Type of plant	Sewered-population equivalent		Typical analytical results	
	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids
	Per 1,000 pounds of milk received		Parts per million	
Receiving station	4	2	500	
Bottling works	6	3		
Cheese factory	16	9	1,000	750
Creamery	6	3	1,250	660
Condensery	7	4	1,300	750
Dry-milk plant	6	3	480	
General dairy	10	5	570	540
	Per 100 gallons			
By-products:[1]				
Whey	160		32,000	
Buttermilk	320		64,000	
Skim milk	365		73,000	

[1] Additional when discharged to sewer.

DESCRIPTION OF PROCESS

Plants handling or processing milk and milk products may be generally classified as—

(*a*) Receiving station.
(*b*) Bottling works.
(*c*) Cheese factory.
(*d*) Creamery.
(*e*) Condensery.
(*f*) Dry-milk plant.
(*g*) Ice-cream plant.
(*h*) General dairy.

The processes involved under each of these classifications are as follows:

(*a*) *Receiving station.*—This is a collecting station for raw milk where milksheds are of such size that the product cannot be brought directly to the processing plants.

The milk is received in cans and the process merely involves dumping, sampling, weighing, cooling to between 35° and 40° F., and loading into tank cars or trucks for shipment to the processing plants. Remaining operations consist of washing of cans, vats, cooling equipment, and floors.

(*b*) *Bottling works.*—Raw milk and cream is received in cans, tank cars, or tank trucks. Process operations consist of can dumping, sampling, weighing, clarification, preheating, filtration, pasteurizing, cooling, and bottling of milk and cream. Other operations include the washing of bottles, cases, cans, vats; apparatus for clarifying, heating, pasteurizing and cooling; and floors.

(*c*) *Cheese factory.*—The raw material is whole milk, and, in some cases, cream or skim milk. The intake milk is weighed, preheated, pasteurized, cooled, and filtered.

Cheese may be classified according to the kind of milk used, the process of making, and the seasoning or ripening. Skim milk, which is either separated from the raw milk or obtained from other sources, is run into vats with whole milk and a "starter" (lactic acid bacteria) is added. The amount of "starter" used runs from 1 to 3 percent of the milk weight. The mixture is allowed to set and ripen at controlled temperatures until proper acidity has developed. Rennet, a substance obtained from the stomach of calves, is then added. This precipitates the casein from the whey, the process taking from 10 to 15 minutes at 86° F. The curd is cut by knives, piled and turned periodically (cheddared) to release entrained whey. After draining and, in some cases, washing, the curd is put in press forms and placed under controlled temperature and humidity conditions for ripening and flavoring. In this process, the casein is peptonized and changed into forms that are digestible, and the characteristic flavors are produced. For processed cheese the ripened product is ground, melted, pasteurized to stop ripening, and packed while hot.

(*d*) *Creamery.*—Whole milk, sour cream, and sweet cream are processed into butter and other products.

The whole milk is separated for its cream content and the byproduct skim milk is disposed of variously to condensing or dry-milk plants. The cream is then "ripened" or soured and the butter churned from the sour cream. On the farm this "ripening" is generally accomplished by allowing the cream to sour spontaneously. In the larger dairies, however, the cream collected from various sources is preheated, filtered, pasteurized, and cooled, and then ripened by means of a "starter." The chances of getting a poor flavor in a large creamery batch are great; hence the "starters" employed are carefully guarded by competent bacteriologists. After ripening the cream is churned. This is merely a mechanical means of demulsifying the fat, the minute globules cohering to form larger and larger globules until a solid mass is obtained. The butter is next kneaded and washed, either in or out of the churn, to remove any remaining buttermilk, and is packed. The buttermilk may be condensed or dried and sold. Its chief use is for stock feeding, with some utilization for baking.

(*e*) *Condensery.*—Whole milk, skim milk, or other dairy products are condensed to produce unsweetened evaporated milk or sweetened condensed milk.

For the production of unsweetened evaporated milk the whole milk is first preheated in a hot well by direct steam in order to inactivate enzymes causing physical and chemical changes and to get desirable physical properties of the final product. The heated milk is then evaporated either by batch evaporation, in which the evaporator is loaded and heat maintained until the charge reaches the desired specific gravity, or by the continuous method, in which the flow through the evaporator is carefully regulated to produce a continuous discharge of evaporated milk having the desired specific gravity.

The evaporator consists of a closed tank heated by coils. The source of heat is generally exhaust steam or hot water from the vacuum pumps and other equipment. A vacuum sufficient to cause the milk to boil at about 135° F. is maintained. Vapors are taken off through a top outlet and condensed by a water spray. In some cases live steam is blown through the milk after evaporation in order to produce the desired consistency, the temperature reaching about 210° F. for a short time.

After evaporation, the milk is homogenized; i. e., forced at high pressures through a closely set valve to break up fat globules and produce a fine suspension. Cans are filled and sealed by machine, after which they are either treated in a continuous sterilizer or a batch sterilizer. In the latter the filled cans are loaded into metal baskets on a wheel rack which revolves in a horizontal closed tank containing enough water to immerse the lower baskets. The steam is turned on and the cans are subjected to contact with the steam and hot water by rotation of the rack. The heat is maintained at about 235° F. for 20 to 30 minutes. The cans are cooled by circulating cooling water, after which samples are incubated at 80° F. for about 3 weeks to disclose any incomplete or improper sterilizing as shown by swelling of cans.

Sweetened condensed milk is produced in the same manner, except that sugar is added in the evaporators, a higher temperature is maintained in order to dissolve the sugar, the milk is evaporated to a greater density and the product is not sterilized after canning, the sugar acting as a preservative. Other condensery products include evaporated or condensed skim milk, whey, and buttermilk.

Remaining operations consist of washing of cans, equipment, and floors.

(*f*) *Dry-milk plant.*—Powdered milk is produced from whole milk, skim milk, or buttermilk by one of the following methods:

(1) Atmospheric drum method: The milk is preheated or condensed as in the production of evaporated milk and then fed through perforated pipes as a thin film to two steam-heated drums revolving toward each other. The regulated clearance between drums assures an evenly spread thin coating which dries quickly. The film is scraped off by a fixed knife and barreled for market.

(2) Vacuum drum method: A single drum revolves in a vacuum chamber. The preheated or precondensed milk is discharged to a delivery tray feeding the revolving drum. The drum picks up a thin film which quickly dries and is scraped off by a knife. This method allows drying at reduced temperatures.

(3) Spray method: The preheated or precondensed milk is atomized and sprayed into a current of heated air passing through the drying chamber, the solids falling to the bottom. Any solids carried off by the air are removed by passing the exhaust through a heavy unatomized spray of incoming milk.

Clean-up washes and rinses of equipment, floors, and receiving room complete the operations.

(*g*) *Ice-cream plant.*—Ice cream and ice-cream mixes are made by combining various forms of milk with sugar, gelatine, eggs, flavoring, and other ingredients. In general, the process consists of mixing the pasteurized milk and cream with the other ingredients, pasteurizing, homogenizing, cooling, measuring, and freezing. Nuts, fruits, and other ingredients which cannot be homogenized are added at the freezer.

Remaining operations are the washing of freezing and receiver units, cans, floors, pasteurizer, and other equipment.

(*h*) *General dairy.*—Manufactures various combinations of some or all of the above products.

Raw Materials and Products

Some relationships between raw materials, products, and employees are given in tables Mk–2 and Mk–3. They are intended to show general relationships only, since considerable variability of product yield exists due to differences in the raw material, the processing methods, quality of the final product, and the use for which it is intended.

TABLE MK–2.—*Ratio of products to raw material*

Process	Raw material	Products (pounds per pound raw material)
Separation	Whole milk (4% ± butterfat)	Cream, 0.12 (30 to 40 percent butterfat). Skim, 0.88.
Cheese making	Whole milk	Cheese, 0.10. Byproduct cream, 0.02. Whey, 0.88.
Do	Skim milk	Cottage cheese, 0.16. Whey, 0.84.
Butter churning	Cream (30 percent butterfat)	Butter, 0.37. Buttermilk, 0.63.
Do	Butterfat	Butter, 1.25.

TABLE MK–3.—*Ratio of employees to raw milk intake*

Type of plant	Number of employees [1]
Receiving station	1.5
Bottling works	8.9
Cheese factory	3.8
Creamery	1.63
Condensery	4.7
Dry-milk plant	3.9
General dairy:	
General average	10.9
Intake less than 10,000 pounds/day	16.7
Intake over 10,000 pounds/day	9.9

[1] Per 10,000 pounds milk intake daily.

Sources and Quantity of Waste

There are several sources of wastes in the dairy industry, the chief of which are as follows:

(*a*) *Whole milk left in cans and equipment.*—In can dumping, particularly where done at a high rate, considerable milk is left in the can and this may go to the sewer through drippings and can washes unless precautions are taken. The loss may vary from 0.1 to as high as 6 percent, averaging about 1 percent. Aside from producing no revenue, it may become an expense through cost of treatment. A small amount of milk may also remain in various piping and continuous flow equipment at the end of a run.

(*b*) *Process operations.*—These may include whey, buttermilk, skim milk, sour cream, and butter and cheese washes. They are not ordinarily discharged as waste and should not be under any circumstances.

(*c*) *Cooling waters.*—The source of this waste is from ammonia and vacuum pan condensers, sterilizers, and pasteurized milk or cream coolers.

(*d*) *Domestic waste.*—Originates in the lavatories, locker rooms, and laundries of the milk plants.

The quantity of wastes discharged from industrial plants processing any particular material will vary widely, depending mainly upon the availability of water and management of water-using operations within the plant. This is particularly true of milk-products plants where rinse and wash waters of continuous flow operations may not necessarily be proportional to production; where cooling and condensing waters may or may not be recirculated in regenerative equipment; and where byproducts such as excess skim milk, whey, and buttermilk may be discharged, contrary to approved methods, to the sewers.

Some average volumes of wastes are given in table Mk–4. Byproducts, such as skim milk, buttermilk, or whey, and cooling waters are not included. These figures are based mainly on data from plants having no waste-treatment facilities. Where such facilities do exist, the volumes will tend to be less since a reduction in quantity of wastes will result in a consequent reduction of treatment costs.

Table Mk–4.—*Ratio of waste volume to raw-milk intake*

Type of plant	Gallons waste [1]	Type of plant	Gallons waste [1]
Receiving station	175	Condensery	[2] 150
Bottling works	250	Condensery-vacuum pan water	[3] 1,500
Cheese factory	200	Dry-milk plant	150
Creamery	110	General dairy	340

[1] Per 1,000 pounds milk intake daily.
[2] Exclusive of vacuum pan water.
[3] In terms of 1,000 pounds milk condensed daily.

Character of Wastes

The wastes consist, for the most part, of various dilutions of whole milk, skim milk, buttermilk, and whey from accidental or intentional spills; drippings allowed to waste by inefficient processing equipment, methods, or operation; washes containing alkali or other chemicals used to remove milk, milk products, and partially caramelized material from cans, bottles, tanks, vats, utensils, pipes, pumps, hot wells, pans, coils, churns, and floors; and process washes of butter, cheese, casein, and other products.

Table Mk–5, taken from studies by Eldridge, shows the character of each of the principal constituents to be found in various combinations and dilutions in milk plant wastes.

Table Mk–5.—*Average analyses of milk and byproducts*

Determination	Constituents in parts per million			
	Whole milk	Skim milk	Butter-milk	Whey
Total solids	125,000	82,300	77,500	72,000
Organic solids	117,000	74,500	68,800	64,000
Fat	36,000	1,000	5,000	4,000
Ash	8,000	7,800	8,700	8,000
Milk sugar	45,000	46,000	43,000	44,000
Protein (casein)	38,000	39,000	36,000	8,000
5-day biochemical oxygen demand	102,500	73,000	64,000	32,000
Oxygen consumed	36,750	32,200	28,600	25,900

The character of the specific wastes is as follows:

(*a*) *Receiving-room can dumping.*—Whole milk wastes are produced through the incomplete recovery of milk from dumped cans. The importance of excluding this from the stream is evident from an inspection of the organic solids and biochemical oxygen demand shown in table Mk–5. Based on an average loss of 1 percent of the milk intake, the effect of discharging milk from incomplete can dumping alone amounts to an equivalent of 6 persons per 1,000 pounds of milk received on an equivalent sewered population biochemical oxygen demand basis.

(*b*) *Process operations.*—

(1) Receiving station: Ordinarily no processing other than cooling is done. Wastes are discus ed under (*a*) and (*c*) of this section.

(2) Bottling plant: Processing consists of heating, pasteurizing, cooling, and bottling. No byproducts are produced. Wastes are discussed under (*a*) and (*c*) of this section.

(3) Cheese factory: Whey is produced from the addition of rennet, cheddaring, and curd cooking. Cheese washes also have the characteristics of a dilute whey. Fish do not survive in some whey and water mixtures, dilutions of the order of 1 to 25, have been found to cause death in a few hours.

(4) Creamery: Butter washes containing buttermilk are commonly discharged. Accidental or intentional discharge of buttermilk creates an exceedingly strong waste as shown by the analyses in table Mk–5.

(5) Condensery: The vapors drawn off the milk in the evaporator are condensed by a cold-water spray resulting in a large volume of condensed vapor and cooling (pan) water. The 5-day biochemical oxygen demand of this mixture varies widely, generally running between 50 and 200 parts per million. Cooling water used to cool the sterilized canned evaporated milk may at times become highly polluted with milk from improperly closed cans. Spills of spoiled milk from these constitute a potential source of strong wastes.

(6) Dry-milk plant: Process wastes are, in general, similar to those from a condensery. However, they may cause added difficulties, depending upon the practice in handling the milk dust on equipment and floors.

(7) General dairy: Process wastes consist of combinations of some or all of the above.

(*c*) *Rinses and washes.*—These are made up of dilutions of whole milk, skim milk, buttermilk, and whey from the rinsing, washing, and sterilizing of containers and equipment, as well as fresh and caramelized milk products and the alkaline washing powders used. The floor washes contain dilutions of these and, in addition, dirt, sawdust, broken glass, and other similar refuse. The dry-milk-plant floor washes may be particularly strong in milk solids where milk dust on equipment and floors is allowed to accumulate. Table Mk–6 presents typical analyses of wastes, including floor washes, from different types of plants.

TABLE MK–6.—*Typical analytical results of milk-plant wastes*

Type of plant	Solids				Oxygen		pH
	Total	Volatile	Suspended	Volatile suspended	Consumed	5-day biochemical oxygen demand	
Receiving station	1,141	844			312	509	
Cheese factory	1,528	917	751	703		998	7.0
Creamery	2,422	1,141	664	483		1,246	7.7
Condensery	2,793	1,233	754	582		1,291	7.8
Dry-milk plant	2,407	540			283	485	
General dairy	1,483	888	536	404		567	5.3

Table Mk–7 gives the average milk-solids content of wastes from various types of plants. Because of the wide variation in individual cases these figures should not be relied upon in the design of waste-treatment facilities. They are given here to serve as a guide in cutting down losses within the processes where individual cases vary widely from the average. Waste volumes and biochemical oxygen demand values are also shown for comparative purposes. The figures are representative of the ordinary wash wastes and process losses, not including byproduct skim milk, buttermilk, or whey except the amounts included in cheese and butter washes.

TABLE MK-7.—*Volume and strength of milk-product wastes*

Type of plant	Total milk solids (parts per million)	5-day biochemical oxygen demand (parts per million)	Ratio biochemical oxygen demand to milk solids	Volume (gallons per 1,000 pounds of milk received)
Receiving station	700	509	0.73	175
Bottling works	600			250
Cheese factory		998		200
Creamery	1,500	1,246	.83	110
Condensery	1,200	1,291	1.08	[1] 150
Dry-milk plant	1,200	485	.40	150
General dairy		567		340

[1] Exclusive of vacuum-pan water; pan waters have a biochemical oxygen demand of 50 parts per million or less and a volume of 1,000 to 1,500 gallons per 1,000 pounds of milk received.

Typical sewered-population equivalents, in terms of biochemical oxygen demand, from various sources are given in table Mk–8. These values represent wash wastes and process losses but do not include byproduct discharges.

TABLE MK–8.—*Typical sewered-population equivalents (biochemical oxygen demand)*

Type of plant	Persons per 1,000 pounds milk intake		
	A	B	C
Receiving station	2.8	4.8	4.4
Bottling works	4.7	5.6	6.2
Cheese factory	16.1		10.0
Creamery		5.0	6.8
Condensery	4.8	6.0	7.2
Dry-milk plant		6.0	3.6
General dairy			9.6
Creamery	9.4 persons per 100 pounds of butter produced		

The variation in strengths of wastes from the various types of milk plants is within the range that can be expected in plants of the same industry. Receiving stations, as might be expected from the fewness of operations, show the lowest sewered-population equivalents while cheese plants, where small amounts of whey are often discharged in cheese-washing operations, show the highest values.

From the analyses given in table Mk–6 the ratio of 5-day biochemical oxygen demand to suspended solids was found to average 1.52. Applying this factor to the biochemical oxygen demand sewered-population equivalents and a correction for per capita daily oxygen requirements, based on 0.167 pound 5-day biochemical oxygen demand and 0.2-pound suspended solids per person, respectively, gives the population equivalent on a suspended solids basis.

By a study and weighing of results from various sources, average population equivalent figures are concluded to be as shown in table Mk–9. Data on suspended solids in the byproducts are not available.

TABLE MK–9.—*Average sewered-population equivalents (biochemical oxygen demand and suspended solids)*

Type of plant	Number of persons		Unit
	Biochemical oxygen demand	Suspended solids	
Receiving station	4	2	1,000 pounds of milk received.
Bottling works	6	3	Do.
Cheese factory	16	9	Do.
Creamery	6	3	Do.
Condensery	7	4	Do.
Dry-milk plant	6	3	Do.
General dairy	10	5	Do.
Byproducts [1]	160		100 gallons of whey.
	320		100 gallons of buttermilk.
	365		100 gallons of skim milk.

[1] Additional when discharged to sewer.

Pollution Effects

Since milk wastes are organic in nature, the polluting effects are almost entirely due to the oxygen demand which they impose on the receiving stream. Fresh wastes may be acid or alkaline. Where receiving waters cannot provide sufficient oxygen for aerobic decomposition the lactose is converted to lactic acid and the wastes become sufficiently acid to precipitate the casein. The heavy black sludge deposits and strong pigpen odors caused by the putrefying casein characterize milk-waste pollutions.

Remedial Measures

The subject of milk-plant wastes, with methods of recovery and treatment, has been extensively studied for years by State and Federal health agencies, experiment stations, and individuals. Many of these developments have been incorporated in full-size treatment works for which results under actual operating conditions are available. For the purposes of this guide such results have been used, where available, to demonstrate the various types of treatment. Remedial measures may be classified as byproduct recovery, or processing and waste treatment.

BYPRODUCT RECOVERY

Byproduct recovery is profitable to the milk-plant operator since it permits a defrayal of part or all of the expense chargeable to waste treatment. There are very few milk plants operating today in which it is not possible to effect an appreciable reduction in milk losses by more careful operation, by the installation of more modern equipment, or both.

Drip savers.—These may be used ahead of the can washers. The equipment is relatively inexpensive and very effective. Another major loss in the milk plant occurs in draining- and washing-equipment operations. Air jets have been used effectively for blowing out the lines of coolers and piping. Small amounts of water for initial rinsing of this equipment washes out the milk not blown out by the air.

That these devices are worth while has been proven by actual installations. At a bottling plant in Pennsylvania catch samples of these wastes during peak operation showed a biochemical oxygen demand of about 1,000 parts per million before the changes were made. An analysis of a composite sample taken after the changes were made showed a biochemical oxygen demand of about 150 parts per million, far less than is normally found in a plant of this type. Tests of the wastes made with and without the equipment rinsings separated gave the results shown in table Mk–10.

Table Mk–10.—*Summary of drip-saver performance, Pennsylvania*

Determination	Results in parts per million		Percent reduction
	Rinsings left in	Rinsings out	
Total solids	869	585	36
Volatile solids	291	90	69
Suspended solids	372	188	49.5
Protein	78	33.5	57
Fat	142	34	76
5-day biochemical oxygen demand	1,000	150	85

Considering that whole milk has a biochemical oxygen demand of 102,500 parts per million, the importance of preventing any of it from reaching the stream is evident. The milk recovered in this manner is generally used for stock feed, most States forbidding its use for human consumption.

Skim milk.—This is not ordinarily discharged as a waste and should not be disposed of in this manner under any circumstances. Where processing is not practiced, it may be returned to the farmer for use as stock feed. However, it may be converted into several useful byproducts, the chief of which are as follows:

(*a*) Chocolate skim-milk beverage: Produced by flavoring skim milk with chocolate and sugar.

(*b*) Skim-milk powder: Produced by hot-roll or spray drying. Its chief uses are in baby foods, ice-cream manufacturing, bread baking, and animal foods.

(*c*) Casein: Precipitated from the skim milk by adding dilute acids or rennet. The casein is separated, washed, and dried. It has a wide variety of commercial uses, principally in the paper industry as sizing for high-grade papers, casein glue, plastics, filler or binder in certain foods, and as a constituent of paints.

(*d*) Albumin: Obtained from the casein recovery whey through coagulation by heating to 70° C. It is not acted upon by rennet or acids at ordinary temperatures. The chief use is as a constituent for poultry feed.

(*e*) Lactose (commonly known as milk sugar): It is peculiar to milk and is found nowhere else in nature. Commercially it is obtained as hard rhombic crystals from the evaporation of the casein and albumin recovery whey. The lactose is readily converted to lactic acid by bacterial fermentation. Lactose and its byproducts are used mainly in pharmaceutical preparations, baby foods, ice-cream sherbets, preserving pickles, olive packing, printing colored fabrics, and deliming of hides in tanning.

Whey.—This byproduct of cheese manufacture, is another material which should not and ordinarily is not discharged as a waste. Small amounts of it are discharged with cheese washes. The presence of even small amounts may upset any of the milk-plant waste treatment methods in use today. Several processes whose function is to reduce the strength of the whey or eliminate it altogether have been attempted and a few have been found practicable.

The two most feasible methods of disposal at present appear to be drying and stock feeding. In the drying method, as practiced at one plant, 100 gallons of fresh whey are mixed with about 80 pounds of corn flour, bran, middlings, or a mixture of these. The thoroughly mixed and thickened whey is pumped upon slowly revolving steam-heated rolls from which it is scraped, carried by a conveyor to a screen, and the screenings bagged or barreled. The yield is about 124 pounds of dried feed per 100 gallons of whey. This product is used chiefly as a poultry feed. Another practice is to run the whey through a separator to recover the cream used in the manufacture of whey butter. The residual whey contains albumin and lactose, which are both recoverable, as discussed under skim-milk processing.

Where recovery by processing is not practiced, the whey may be sold or given to farmers as stock feed or it may be disposed of by irrigation on isolated farm land.

Buttermilk.—The methods for disposing of excess buttermilk and butter wash waters are similar to those for the disposal of whey. The buttermilk may be evaporated to a semisolid, in which form there is a demand for stock feeding, or it may be converted into a poultry feed by hot-roll drying. When no processing is done, disposal may be to farms as stock feed.

TREATMENT

Where byproduct recovery is not practiced or is insufficient, treatment is necessary. In the following paragraphs are discussed important features of the more common methods as well as typical installations.

(*a*) *Dilution.*—The process consists of discharging the wastes in such a manner as to enable their being cared for either by a stream or municipal treatment plant. This is done by using a holding tank of such size and outlet facilities that the raw wastes may be discharged over a longer period of the day than that in which produced. Provision should be made for aerating or circulating the tank contents or chlorinating the influent in order to keep the wastes fresh and delay decomposition during the holding period.

(*b*) *Irrigation.*—This method is applicable to small plants located on farms or in outlying districts where the waste may be spread over land under constant cultivation or on isolated waste land. A sandy soil is required. Odors may be controlled by the use of sodium hypochlorite or chloride of lime. The method is generally used only during the summer months when stream flows are low.

(*c*) *Imhoff tanks.*—This type of treatment is not considered to be of much value for milk-plant wastes. Upon entering the tank the milk or cream begins to sour and the suspended matter formed, having a low specific gravity, rises to the surface and forms a scum in the flow section. The solids adsorbed by this scum cause the clogging of filter units. Also, the acidity developing as a result of storage inhibits bacterial activity. The Imhoff tank soon becomes, in reality, a septic tank.

(*d*) *Septic tanks.*—Opinion is divided on the value of septic tanks when applied to milk-plant waste. Eldridge states that the septic process cannot be successfully applied to milk waste, since products are formed by septic fermentation of

milk solids that are more detrimental to the stream than the fresh solids. Trebler is of the opinion that when strong wastes are removed, the proportion of cleaning alkalis to milk sugar becomes larger and gives the septic tank an opportunity to work, especially if the pounds biochemical oxygen demand load per unit volume tank capacity is kept within the limits for domestic waste and if the tank is seeded properly initially. Under these conditions it is reported that good reduction in fat and suspended matter and from 30 to 50 percent reduction in biochemical oxygen demand may be expected.

A large number of septic tanks are still in use, either alone or as pretreatment for removal of the gross solids before application of wastes to filters. Table Mk-11 summarizes the performance of the septic-tank treatment plant at a milk receiving station in Moravia, N. Y.

TABLE MK-11.—*Summary of septic-tank performance, New York*

Determination	Raw waste (parts per million)	Septic-tank effluent (parts per million)	Reduction percent
Total solids	1,141	727	36
Volatile solids	844	337	60
Organic nitrogen	27.18	4.68	83
Free NH_3	1.5	20.0	[1] 1,200
Oxygen consumed	312	65.9	78
Chlorine demand	14.4	24.9	[1] 73
1-day biochemical oxygen demand	48.3	114	[1] 136
5-day biochemical oxygen demand	509	395	22

[1] Increase.

(*e*) *Anaerobic stabilization.*—Buswell found, from experimentation with whey and buttermilk, that by feeding these raw untreated materials to an anaerobic digestion tank (or two in series) at rates of from one-twentieth to one-thirtieth of the tank volume per day about 95 percent reduction in pollutional strength could be obtained. He reports that from 8.3 to 12.4 cubic feet of gas having a British thermal unit content of 550 can be recovered at a moderate cost per pound (dry weight) of milk solids The tank effluent was neither sour (pH 7.0 to 7.5 and volatile acids as acetic, amounted to only 500 to 1,850 parts per million) nor highly putrescible, and contained but little settleable solids. The required tank size (or sizes if operated in two stages) would be 5.7 cubic feet per pound of waste milk solids per day. It was suggested that in most cases the tank effluents be further treated by application to slag, stone, lath, or sand filters; by discharge to city sewers and subsequent treatment; or to streams having sufficient flow. Relative initial costs of treatment plants per pound of milk solids applied per day were given as follows:

Fermentation tank alone	\$2.86
Fermentation tank plus tricking filters	8.70
Fermentation tank plus sand filters	17.46
As compared with—	
Trickling filters alone	116.80
Sand filters alone	292.00

Trebler commenting on this method states that with the present great excess of whey solids and the low prices paid, such a process might be economical and that a cheese factory could probably make enough gas for its fuel needs. The process is not known to be in commercial use in the milk industry.

(*f*) *Biological filtration.*—The use of filters has received very extensive study and has been found to be the most generally applicable treatment method for milk wastes.

Eldridge found that reductions of 65 to 70 percent of the biochemical oxygen demand were possible in the operation of a standard filter (operated at about 1 million gallons per acre per day without recirculation) on raw wastes having a 5-day biochemical oxygen demand of between 500 and 800 parts per million. In general, strong wastes cannot be applied with success. Kimberly cites a tentative limit of 800 parts per million 5-day biochemical oxygen demand for successful operation at a rate of 1 million gallons per acre per day. Wastes of greater strength may be diluted with cooling or pan waters before application to the filter. On the basis of milk solids applied, Agar reports that satisfactory operation

generally will result if the rate of application is not over 1 pound of milk solids per 80 cubic feet of filter volume per day for filters 6 to 10 feet deep. Levine found application of wastes in small amounts at frequent intervals to be more effective than large amounts applied at longer intervals. The revolving distributor possesses advantages over the fixed nozzle and tipping trough distributors in this respect.

The removal of gross suspended solids before filtration will help prevent filter clogging. Secondary settling is desirable to eliminate filter sloughings from the final effluent. Ventilation of filters is also desirable and has been accomplished by building filters above ground with wire-net side walls, or by using cement block wtih open joints.

The type of filters which have received the most extensive study are as follows:

(1) Lath trickling filter, as described by Frank and Rhynus, has been suggested as a treatment method for small plants. It can be cheaply constructed and maintained with readily available materials. The filter is dosed by a tipping trough. Such units should be housed to prevent freezing and help control odor nuisance. The use of a holding tank to smooth out application of waste and spread the discharge over several hours each day is advisable.

(2) Sand filters: Hommon, as a result of sand-filter studies (1915–17), recommended underdrained sand filters consisting of 1-foot coarse stone overlain by 4 feet of sand dosed at a rate of 50,000 gallons per acre per day. A septic tank designed for 48-hour detention with a 30 percent additional volume for sludge and scum accumulations was to be provided for primary treatment. Walker also found sand filters applicable and successful at rates of 75,000 to 100,000 gallons per acre per day.

It is likely, however, that with the development of the higher rates on the coarse media, the sand filter is too limited by cost and space requirements to offer any competition.

(3) Coarse media filters: Slag and stone are commonly used for tricking filter materials. Levine studied the effects of various filter media experimentally. The removals obtained are shown in table Mk–12. The experiments were performed on raw skim milk wastes with biochemical oxygen demands varying from 200 to 1,600 parts per million and were applied at a rate of 550,000 gallons per acre per day. The experimental filters were 2 feet square and 6 feet deep.

The cinders, while giving high efficiencies, clogged frequen ly and washing was necessary after 5 months operation. Corncobs gave good removals although no nitrates were formed. The bed shrank 35 percent in depth and efficiency decreased sharply at the end of a 9-month test. The 3-inch spiral ring packing was considered too large for outstanding results. It was thought that excellent results would be obtained on smaller rings.

Perforated tin cans have also been tried experimentally. With three of these filters, each 2 feet in diameter by 6 feet deep, in series and dosed at a rate of 5 million gallons per acre per day, a removal of 1 pound of biochemical oxygen demand per 8 cubic feet of filter volume was accomplished without dilution or recirculation.

A filter volume of 80 cubic feet per pound of milk solids applied for filters 6 to 10 feet deep is commonly referred to in design. In all cases the removal of the larger suspended solids prior to application on the filter, and final settling to collect filter sloughings, is desirable.

TABLE MK–12.—*Biological oxygen demand removals on various filtering media*

Filter medium	Biochemical oxygen demand			pH—Effluent (raw pH-6.7)
	Raw waste (parts per million)	Effluent (parts per million)	Removal percent	
Lath (sectional)[1]	565	28.9	94.9	7.8
Cinder (sectional)	565	13.6	97.6	7.7
Do	508	20.1	96.0	7.8
Cinder (solid)	508	10.6	97.9	7.8
Gravel	513	15.5	97.0	7.8
Spiral rings	513	105.0	79.5	7.7
Corncobs	761	63.0	91.1	8.1
Broken tile	761	31.5	95.6	8.2
Cinder	1,000	8	99.2	8.2
Quartzite	1,000	144	85.8	8.2

[1] Six 1-foot layers of lath (or cinders) each separated from the succeeding layer by a 4-inch air space.

(4) High rate recirculating filters: Recent studies on high-rate application and recirculation of a mixture of raw waste and a portion of the filter effluent has demonstrated the possibility of both producing higher removal efficiencies and reducing the size of filter required. The strength of the effluent produced depends on the initial strength of the raw waste and the number of times circulated. This makes possible the treatment of strong raw wastes without dilution and, by sufficient recirculation, the production of highly purified effluents.

Halvorson obtained experimental reductions of 85 to 95 percent operating on wastes having biochemical oxygen demands of 2,500 to 3,500 parts per million. The filter material used was specially fabricated tile laid vertically to form a series of vertical conduits 1 inch in diameter. This was reported to minimize channeling and ponding, and to give a larger surface area per cubic foot than average filter stone. The filter was ventilated by use of a fan. For very strong wastes, it was found desirable to pretreat them in a septic tank by allowing souring, with resultant precipitation of casein, to take place. The tank effluent (pH = 4.5) was mixed with a portion of the filter effluent (pH over 7.0) and applied by means of a revolv- inverted cone distributor above the center of a circular bed.

Eldridge investigated recirculating filters both on a continuous flow and a fill-and-draw basis. In the continuous recirculation studies it was found that the number of times the waste was recirculated had a greater effect on the filter efficiency than the loading and that with a given number of recirculating cycles the effluent obtained was about the same regardless of the raw strengths applied. A series of tests were run on a filter 6 feet deep and 20 square feet in area. The filtering material used was 1 foot of 3½-inch stone overlain by 5 feet of graded 1½-inch to 2½-inch gravel. Provision was made for natural ventilation. The waste was pumped from a storage tank to an orifice box from which a measured quantity flowed to a pump sump for mixing with part of the settled filter effluent. This was applied to the filter continuously by means of a rotary distributor. A quantity of settled effluent equal to the raw waste influent was discharged and the remainder returned for recirculation. The results obtained from a series of runs at each of 3 rates of raw waste application and recirculation (in this case these were interdependent in that the total application; i. e., raw waste plus return effluent, was equal to 20,000,000 gallons per acre per day for each run) on raw wastes ranging from 331 to 1,330 parts per million, 5-day biochemical oxygen demands gave removals of 21.0 to 92.8 percent. The average results obtained from each of the three series are shown in table Mk-13.

TABLE MK-13.—*Performance of continuous high-rate trickling filter*

Filtration rate (million gallons per acre per day)		Times recirculated	5-day biochemical oxygen demand			Biochemical oxygen demand loading	
Raw	Applied		Raw (parts per million)	Filtered (parts per million)	Reduction percent	Pounds per cubic feet	Cubic feet per pound
4.9	20.0	4.0	508	267	47.4	79.6	14.4
3.4	20.0	6.0	417	146	65.0	44.3	31.9
2.4	20.0	8.3	714	118	83.5	52.6	21.5

The saving in filter size is apparent from the above, an average of 83.5 percent biochemical oxygen demand removal being obtained with a filter volume of 21.5 cubic feet per pound of biochemical oxygen demand applied. Filters of this type give reported removals equivalent to those of standard trickling filters while using a filter volume of one-half to one-third that of the standard filter. The efficiency of existing standard filters may be increased by a change-over to provide for recirculation.

Studies were also conducted by Eldridge on the application of this principle on a fill-and-draw plant which might satisfy the needs of a small dairy. Tests were made on a stone filter of the same depth and filling materials as used for continuous recirculation. Raw wastes ranging from 237 to 2,100 parts per million biochemical oxygen demand were recirculated from 4 to 36 times. Reductions in biochemical oxygen demand ranged from 47.4 percent on raw wastes averaging 508 parts per million biochemical oxygen demand recirculated 4 times to 98.3 percent biochemical oxygen demand reduction on raw wastes averaging 1,780 parts per million biochemical oxygen demand recirculated 33 times.

The plant suggested as a result of these tests consists of a hopper bottom tank of capacity equal to the volume of waste produced during 1 day, a small pump, rotary distributor, and a filter 6 to 7 feet deep and of such area as to provide 1 square foot of surface area per 30 to 35 gallons waste produced daily. Filtering material is 2 to 3½ inch stone. Rate of application should be about 20 to 25 gallons per square foot per hour. In operation, the tank would be emptied each morning and filled during the day, the waste being applied to the filter continuously. Sludge is withdrawn from the hopper bottom to a sludge pit before drawing off the treated waste.

Studies were made at a receiving station and milk-powder plant in Elba, N. Y. The whole milk intake was 69,300 pounds per day and wastes amounted to 58,500 gallons per day. The trickling filter is 8 feet deep and operates 18 hours per day at a rate of 2.8 million gallons per acre per day or 140 cubic feet per pound of milk solids. Results of analyses, obtained by averaging a series of catch and composite samples for a 2-day period, after 2 months' operation, are presented in table Mk-14.

Hatch and Bass conducted an investigation of the waste-disposal facilities of the Pet Milk Co., at Coldwater, Ohio. The plant is modern in every respect and is equipped to handle a whole-milk intake of 300,000 pounds per day. The principal product is canned evaporated milk, although some ice-cream mix is manufactured and equipment is available for producing skim-milk powder.

TABLE MK-14.—*Trickling filter performance, milk receiving station and powder plant, New York*

Determination	Raw waste (parts per million)	Filter effluent (parts per million)	Reduction (percent)
Total solids	2,407	2,094	13
Volatile solids	540	299	45
Total nitrogen	22.4	8.0	64
Oxygen consumed	283	103	64
Chlorine demand	4.8	25.8	[1] 538
1-day biochemical oxygen demand	67.5	23.6	65
5-day biochemical oxygen demand	485	56.3	89

[1] Increase. Probably due to break-down of sulfates.

Industrial wastes, averaging 30,800 gallons per day during the tests, are made up of floor and equipment wash water, wastage from the condensing water recirculation system, and sludge from the lime-soda softening of the boiler water. Treatment facilities consist of a primary settling tank, an excess raw waste storage basin, settled waste pumps, trickling filters, and secondary settling tank. Raw waste, after preliminary settling, is diluted with pan water, plant effluent, or a combination of both before being applied to the trickling filter. The ratio of applied waste to raw waste is about 12 to 1.

Operating results, obtained from the average of a 30-day series of samples composited in proportion to the flow, are presented in table Mk-15.

TABLE MK-15.—*Trickling filter performance, condensed milk plant, Ohio*

[Results (except pH) in parts per million]

	Raw waste	Filter influent	Filter effluent	Final effluent
Total solids	2,793	1,687	1,628	1,628
Volatile solids	1,233	346	296	276
Suspended solids	754	51.1	17	14
Volatile suspended solids	582	41.6	13	11
5-day biochemical oxygen demand	1,291	56.5	8.3	6.4
pH	7.8	7.2	8.0	8.0

Ruf and Warrick studied the characteristics of a condensed-milk waste treatment plant at Chilton, Wis. The average milk intake during the study was about 163,000 pounds daily, the maximum capacity of the dairy being 200,000 pounds per day. Cooling and condensing waters from the pan are discharged directly to a nearby creek, all other wastes passing through the treatment plant. Facilities include a hopper bottom storage tank, rotary distributor, an uncovered circular filter, and a hopper bottom secondary settling tank. The filter is built entirely above ground. Its walls are made of pipe uprights embedded in a concrete curb and supporting ¾-inch chicken wire strengthened by fence wire.

Average results from six complete tests of operation are given in table Mk–16. Winter samples taken when air temperature was about 46° F. and the influent and effluent temperatures 57° and 41° F., respectively, showed a 5-day biochemical-oxygen-demand reduction for a raw waste of 1,490 parts per million of 82 percent. Little difficulty was encountered with this open filter in two winters of operation.

TABLE MK–16.—*Trickling filter performance, condensed-milk plant, Wisconsin*

Item	Unit	Filter influent	Filter effluent	Final effluent	Percentage removals	
					Filter	Final
Dosage rate	Million gallons per acre per day.	0.75				
Do	(1)	96				
Dosage cycle:						
On	Minimum	8				
Off	do	7				
5-day biochemical oxygen demand.	Parts per million	628	87	52	86	92
Oxygen consumed	do	863	218	175	75	80
Total organic nitrogen	do	36	16	14	55	61
Free NH_3	do	38	1.8	2.3		
Nitrite nitrogen	do		1.4	1.3		
Nitrate nitrogen	do		3.0	2.7		
Total solids	do	2,442	1,859	1,823	24	25
Volatile solids	do	1,206	613	588	49	51
Soluble solids	do	2,061	1,661	1,659		
Suspended solids	do	381	196	164	49	57
Volatile suspended solids	do	376	164	136	58	64
Average pH		7.1	8.1	8.1		
Average D. O.	Parts per million		5.9	5.9		
Reducible sugars	do	121	0	0		
Temperature	° C	21	17	17		

1 Cubic feet of filter per pound of 5-day biochemical oxygen demand per 24 hours.

Eldridge converted a low-rate trickling filter into a high-rate recirculating filter at Perinton, Mich. The filter had been operated for several years as a standard filter and the best removal of biochemical oxygen demand ever obtained was 60 percent. At present the wastes pass through a rough screen to a holding tank, with a capacity of about one-half the daily flow. A centrifugal pump applies this effluent through a rotary distributor at a net rate of 3.4 million gallons per acre per day or a gross rate of 16 million gallons per acre per day, giving a ratio of applied waste to raw waste of 4.7 to 1. The filter effluent discharges through a secondary settling tank to a nearby stream. Average operating results, based on a 9-day series of composited hourly samples proportioned to the volume of wastes at the time of collection, are shown in table Mk–17:

TABLE MK–17.—*Performance of high-rate recirculating trickling filter, Michigan*

Determination	Biochemical oxygen demand	Suspended solids
Raw waste ... parts per million	537	484
Filter influent ... do	106	140
Filter effluent ... do	44	91
Final effluent ... do	46	92
Over-all reduction ... percent	90.6	77.1

A few accounts of British installations and experiments with trickling filters are available. The report of the British Water Pollution Research Board for 1939 contains an account of experiments on the treatment of whey washings from a cheese factory by two-stage trickling filters and by activated sludge. The two-stage filters, operating at 160 imperial gallons per cubic yard of filter medium, produced an effluent of 70 parts per million from whey washings of 270 parts per million. The activated sludge process reduced the biochemical oxygen demand of the washings from 660 to 60 parts per million, using a 36-hour aeration period. Scarlett describes a plant in which wastes are subjected to a 1-day aerobic fermentation at 30° C., sedimentation, straining through coconut-fiber mats, and treatment on trickling filters. Biochemical-oxygen-demand values of 400 to 800 parts per million in the raw waste were reduced to 10 parts per million in the effluent.

(*g*) *Activated sludge.*—While this method of treatment is not new for industrial wastes in general, it has not been used extensively for milk-factory wastes.

At New Bremen, Ohio, activated-sludge treatment is being used on wastes from a dairy whose chief product is butter, but which also manufactures sweetened and unsweetened skim condensed milk, whole milk and skim-milk powder, ice cream and ice-cream mix, and semisolid buttermilk. The averages shown in table Mk–18 were obtained from analyses of a 29-day series of samples composited in proportion to flows. During the tests the daily intake averaged 69,133 pounds of whole milk and 21,065 pounds of sour cream while the waste flow averaged 29 700 gallons per day.

TABLE MK–18.—*Performance of activated-sludge plant, creamery and general dairy, Ohio*

[Results, except pH, in parts per million]

Determination	Raw waste	Primary tank effluent	Final effluent
Total solids	2,422	1,915	1,345
Volatile solids	1,141	726	238
Suspended solids	664	243	30.3
Volatile suspended solids	483	169	25.9
5-day biochemical oxygen demand	1,246	734	12.4
pH	7.7	7.5	8.1

Another plant at which treatment of dairy wastes, by the activated-sludge process, has been successful is located at Somerset, Pa. The chief output is bottled milk, but cream, butter, cheese, ice cream, and condensed milk are also produced. The average intake is 60,000 pounds of milk daily and the average waste flow to the treatment works is 50,000 gallons per day. Typical operating results at this plant are as follows:

	5-day biochemical oxygen demand (parts per million)	Total solids (parts per million)	pH
Raw waste	545	797	7.2
Final effluent	7.4	466	7.7
Percent reduction	98.4	41.5	-------

A recent development is the Mallory process employing the activated-sludge process followed by chemical precipitation with lime and alum. Treatment takes place in two prefabricated steel units, the first being an aerator-clarifier (or first-stage) unit and the second being the chemical precipitation (or second-stage) unit. The dairy produces bottled milk, ice cream, and cottage cheese. The daily milk intake varies from 8,800 to 10,600 pounds. A survey of the plant made on 2 successive days yielded the results shown in table Mk–19:

TABLE MK-19.—*Performance of Mallory process, general dairy*

Determination	First day		Second day	
	Raw waste	Final effluent	Raw waste	Final effluent
Total solids—parts per million	940	505	1,180	465
Volatile solids—do	700	110	900	110
Suspended solids—do	450	25	380	20
Volatile suspended solids—do	420	29	380	15
5-day biochemical oxygen demand—do	969	6	890	5
pH	5.2	8.1	4.4	8.4
Wastes—gallons per day	22,690		15,720	

(*h*) *Guggenheim process.*—This type of treatment, essentially a combination of the chemical precipitation and activated-sludge processes, has been most successfully used for cheese-plant wastes. The wastes are discharged to a storage tank and kept fresh by agitation with air, then flow to the flash mixer where hydrated lime, a ferric salt, and return sludge are added. This is followed by about 4 hours' aeration and, finally, secondary settling.

Eldridge conducted a series of studies on an experimental plant at Clare, Mich. The wastes were typical of those from a cheese factory, consisting of can, equipment, and floor washings as well as sour washings from the cheese and vats. The cheese washings contain some whey and it was the presence of this which made treatment difficult. The conclusions drawn from these studies were as follows: The process can be successfully used for the treatment of cheese-factory wastes. The wastes can include the cheese washings but very little if any, of the whey. The upper limiting biochemical oxygen demand value is about 3,000 parts per million. Return sludge should be about 33 percent of the waste volume. Proper diffusion of sufficient air is necessary to maintain dissolved oxygen in the aeration tank; and conditions must be carefully controlled if good removals are to be obtained. Average operating results are given in table Mk–20.

TABLE MK-20.—*Operating results of Guggenheim process, cheese plant, Michigan*

Determination	Minimum	Maximum	Average
Aeration period—hours	4.5	4.5	4.5
Lime—parts per million	230	400	280
Ferric chloride—do	25	87	56
pH	6.5	7.5	7.3
5-day biochemical oxygen demand, influent—parts per million	1,200	3,400	2,147
5-day biochemical oxygen demand, effluent—do	100	400	229
Total solids, influent—do	1,716	5,792	2,787
Total solids, effluent—do	1,210	1,580	1,401
Settleable solids, aeration tank—do	50	200	105
Suspended solids, aeration tank—do	1,300	3,200	2,150
Dissolved-oxygen aeration tank—do	0	6.0	1.1

Hatch and Bass investigated the waste treatment works of a plant manufacturing American cream cheese at Glen Karn, Ohio, and employing the Guggenheim process. Operation involves the agitation of raw waste in the primary storage basin with air to keep the solids in suspension and the discharge of a constant quantity of raw waste from this tank to the flash-mixing basin through an orifice box discharging at a constant head. The waste discharging through the orifice flows through a second brass-plate screen with slotted openings 1/16 by 3 inches in size to the flash mixer. Here a milk of lime slurry, an iron-salt solution, and return sludge from the final settling tank are added and mixed by air through a perforated pipe. The waste then passes to an aeration basin, having a 4-hour detention period, and finally to a hopper bottom final settling tank with a 2-hour detention period. The average daily flow of wastes during the tests was 15,570 gallons while the average daily intake was 25,563 pounds whole and 5,792 pounds of skim milk. Average operating results, as determined from a 30-day series of samples, composited in proportion to flow, are given in table Mk–21.

TABLE MK-21.—*Operating results of Guggenheim process, cheese plant, Ohio*

[Results, except pH, in parts per million]

	Raw waste	Plant effluent	Percent production
Total solids	1,246	1,027	17.5
Volatile solids	663	353	46.7
Suspended solids	352	120	66.0
Volatile suspended solids	308	88	71.5
5-day biochemical oxygen demand	755	167	78.0
pH	6.7	7.6	

The failure of this plant to give the expected efficiency is said to be chiefly due to: Insufficient training of and attention by the operator; uneven application of chemicals; difficulty in estimating the amount of returned sludge; lack of a primary settling tank to reduce the suspended solids and oxygen demand of the raw wastes; and too short a detention period in the aeration unit.

TREATMENT COSTS

Available installation, operating, and maintenance costs for the various types of plants discussed are given in table Mk-22. Operating and maintenance costs, in general, include labor, power, chemicals, depreciation, and interest.

TABLE MK-22.—*Installation and operating costs: Milk-waste treatment plants*

Treatment process	Milk intake, thousands of pounds per day	Waste flow, gallons per day	Installation cost	Operation and maintenance, per day
Trickling filter [1]	125.0	30,800	$28,800	$13.12
Do	20.0	3,200	4,000	1.50
Do	50.0	8,000	5,500	1.92
Do	100.0	16,000	8,000	2.60
Do	200.0	32,000	11,500	3.84
Do	300.0	48,000	14,500	5.20
Activated sludge [1]	90.2	29,700	15,000	13.86
Do.[1]	60.0	50,000	12,000	
Mallory [1]	9.7	20,000		[2] 2.55
Guggenheim [1]	31.4	15,570	5,300	4.91
Do.[1]	30.0	15,000	8,000	6.00

[1] Actual installation.
[2] Cost is $2.09 when chemical precipitation is not used.

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Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–4

INDUSTRIAL WASTES (*Not an actual dairy*)

River Mileage Index No. *AB–213.4*

Type of Plant: *General Dairy.* State: *Ohio.*
Name of Plant: *Frank Milk Company.*
Municipality: *Larson.* Main Watershed: *Atlantic River.*
County: *Buckman.* Subwatershed: *Blue Creek.*
Address: *762 River Street.*
Source of Information: *A. B. Charles, General Manager.*
Plant Operation:
24 hrs. per day, 7 days per week.
18 Plant employees, maximum—25.
Seasonal Variation:
Peak in June and July.
Minimum in January.

(Survey report continued on next page)

Survey by *D. E. Fleming.* Date: *8–13–40*

Sewered Population Equivalent Computation:
Factors used *per 1,000 pounds milk intake per day:*
B. O. D.: *6.* Suspended solids: *3.*
Sewered population equivalent* based on B. O. D.: *100.*
Sewered population equivalent* based on suspended solids: *Less than 50.*
Remarks --
Computation by *G. H. Irwin.* Date: *11/21/40.* Cincinnati Office

*Rounded to nearest 100.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used become available.

(*Typical inspection report inspection sheet*)

Frank Milk Co. AB–213.4

Water Supply:

	Gallons per day		Source	Treatment
	Average	Maximum		
Drinking	500	700	City	None.
Industrial	1, 800	2, 500	Well	None.
Cooling	15, 000	20, 000	do	None.

Raw Materials:
Average: 13,700 pounds raw milk daily.
Maximum: 23,000 pounds raw milk daily (May and June).

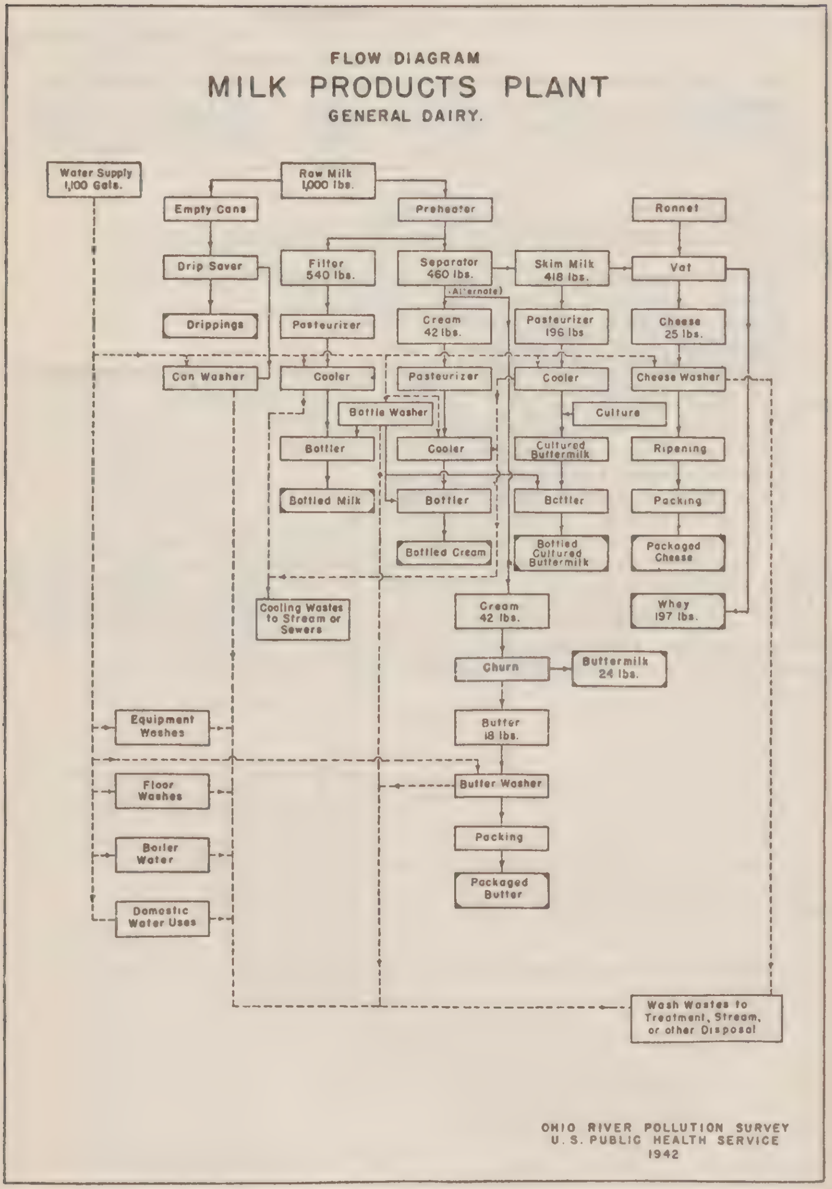
Products:
Bottled pasteurized milk: 1,600 pounds per day.
Bottled pasteurized cream: 1,000 pounds per day.
Butter: 125 pounds per day.
Condensed Milk: 165 gallons per day.
Cheese, buttermilk, and raw milk sold in bulk account for remainder of intake. No estimate of quantities.

Wastes: Total, 16.800 gallons per day.
Can washings: 500 gallons per day.
Churn washings: 100 gallons per day.
Floor washings: 1,000 gallons per day.
Pasteurizer washings: 200 gallons per day.
Condenser cooling: 15,000 gallons per day.
Buttermilk, whey, sour milk, and sour cream used for stock feed.
No spills were reported. Wastes are discharged untreated.

Outlet: 20-inch circular tile sewer in back of plant carries all wastes to Blue Creek. Gaging possible by placing weir in manhole between plant and river. Milky discoloration and some black deposits on bank of stream below outlet.

Sanitary Sewage: Discharged to municipal sewer in front of plant.

Remarks: Company does local business. Some expansion contemplated in the near future.


FLOW DIAGRAM
MILK PRODUCTS PLANT
GENERAL DAIRY.
Water Supply 1,100 Gals.
Raw Milk 1,000 lbs.
Empty Cans
Preheater
Rennet
Drip Saver
Filter 540 lbs.
Separator 460 lbs.
Skim Milk 418 lbs.
Vat
(Alternate)
Drippings
Pasteurizer
Cream 42 lbs.
Pasteurizer 196 lbs
Cheese 25 lbs.
Can Washer
Cooler
Pasteurizer
Cooler
Cheese Washer
Bottle Washer
Culture
Bottler
Cooler
Cultured Buttermilk
Ripening
Bottled Milk
Bottler
Bottler
Packing
Bottled Cream
Bottled Cultured Buttermilk
Packaged Cheese
Cooling Wastes to Stream or Sewers
Cream 42 lbs.
Whey 197 lbs.
Churn
Buttermilk 24 lbs.
Equipment Washes
Butter 18 lbs.
Floor Washes
Butter Washer
Boiler Water
Packing
Domestic Water Uses
Packaged Butter
Wash Wastes to Treatment, Stream, or other Disposal
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1942

MILK PLANT WASTES (Not an Actual Plant)

Plant Frank Milk Co. State Ohio Ref.No. AB - 213.4

City Larson County Buckman Main Watershed Atlantic River

Address 762 River Street Sub-watershed Blue Creek

Informant A. B. Charles Title General Manager Principal Product General Dairy Products

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	168	365	18
Maximum	168	365	25

Seasonal variation Peak in June & July; Minimum in January

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City	500	700	None
Industrial	Well	1,800	2,500	None
Cooling	Well	15,000	20,000	None

RAW MATERIALS:- Lbs. per day		Milk	Cream
Average		13,700	None
Maximum		23,000	None

PRODUCTS:- Bottled Milk Pasteurized 1,600 lb./day Cream Pasteurized 1,000 lb./day

Butter 125 lb./day Cheese No estimate Whey

Buttermilk No estimate Milk powder None

Skim Cond. 165 g.p.d. Other Some raw milk sold in bulk.

WASTES:- Quantity 16,800 g.p.d. How estimated Water bills & pump capacity

Churn washings 100 gal. per day Pasteurizer washings 200 gal. per day

Floor washings 1,000 g.p.d. Sour cream To stock feeding

Buttermilk To stock feeding Whey To stock feeding

Dryer residue None Spills None reported

Disposal other than water carried None

Segregation of Strong Wastes None

Difficulties

Treatment None

Analyses: Number None Date By whom

OUTLET:- Where to Blue Creek

Description:	Size and shape	Material	Location	Elevation
1.	20" circ.	Tile	In back of	
2.			plant	
3.				

Gaging possibilities Good. Could place weir in manhole at outlet sewer.

Conditions below outlet: Color Milky discoloration along bank

Turbidity Deposits Some solids - black

SANITARY SEWAGE: Disposal Municipal Sewer Persons tributary 25

REMARKS Can washings - 500 g.p.d. Company does local business. Some expansion contemplated in the near future.

Survey by D. E. Fleming Date 8-13-1940

APPENDIX IX OF SUPPLEMENT D

OIL

An Industrial Waste Guide to the Oil Industry

CONTENTS

Abstract

Oil-refining processes vary greatly with the type of crude oil being used and the finished products desired. New processes are continuously being devised and old processes changed to meet the shifting demand for various petroleum products. Some refineries merely distill the crude oil to separate the various fractions and sell these after processing to remove certain impurities or objectionable characteristics. The larger refineries crack or otherwise change the chemical structure of one or more of the fractions to increase the yield of the more valuable products such as gasoline.

Wastes from oil refineries contain: (*a*) Free and emulsified oil which may form an unsightly film on the surface of the receiving body of water, coat objects with which it comes in contact, retard atmospheric reaeration, occasionally constitute a fire hazard, and generally interfere with normal water uses; (*b*) substances which may cause tastes and odors in water supplies; (*c*) substances which tend to deplete the dissolved oxygen content of the receiving body of water; and (*d*) suspended matter which may form sludge deposits on the bottom of a stream. In general, the oil refinery pollution corrective measures have been directed at the first two types of substances since they are usually of greater importance, and the removal of oil and of substances causing tastes and odors will ordinarily also reduce the oxygen demand and suspended solids content of refinery wastes.

The waste flows from oil refineries are large, averaging 770 gallons per barrel of oil processed at 41 refineries in the Ohio Basin. If the water is not reused, cooling water accounts for about 80 to 90 percent of the waste flow. The biochemical oxygen demand of the combined wastes is relatively low, usually ranging from 10 to 30 parts per million, and the suspended solids content is usually within the range of 25 to 75 parts per million. Reliable data on sewered population equivalents are limited. The Ohio River Pollution Survey has used values of 600 per 1,000 barrels per day based on biochemical oxygen demand and 1,200 per 1,000 barrels per day based on suspended solids, as approximations to facilitate comparison of the polluting effects of oil refinery wastes with those from other sources.

Sedimentation and flotation basins for separating the oil, water, and settleable solids of the wastes are standard refinery items of equipment. The Committee on Disposal of Refinery Wastes of the American Petroleum Institute has studied

the question of separator design extensively and has developed an efficient separator which is reported to produce an effluent containing only 15 parts per million of oil when operating under favorable conditions. Most of the refineries in the Ohio Basin have rather inefficient separators, inadequate in size and operated with little attention.

The removal of emulsified oil or the prevention of emulsions, and the removal of substances causing tastes and odors, can be done most easily and effectively by segregating the offending waste and treating it separately. Numerous methods are available for treating these wastes. One of the most troublesome effluents is the caustic waste from chemical treatment of gasoline and other oils.

Brines from oil fields cause considerable damage to water supplies, agriculture, fish, and other aquatic life. The principal methods of disposal are storage with regulated outflow and return of the brines to suitable underground formations. The latter method is preferable but is not, at the present time, universally practicable. The practice is relatively new and further development may extend its applicability. Brine production often can be minimized by proper well operation and reworking to seal off the water.

Description of Process

Crude oil is delivered to the refinery by pipe line, tank cars, or tank ships, from which it is transferred to refinery storage tanks and to refinery processes.

Refining of oils consists usually of fractional distillation to separate the various hydrocarbons, application of heat and pressure with or without the use of catalysts to alter the molecular structure of some of the distillation products, and chemical and mechanical treatment of various fractions or products to remove impurities.

The specific processes used vary greatly, depending upon the composition of the crude oil being processed and the products desired. The increasing demand for high-test motor fuel and aviation gasoline has brought about the development of numerous processes for increasing the yield of these products.

Crude oils are roughly classified in American practice according to the nature of the residuum left by nondestructive distillation, such as paraffin base, asphaltic base, or mixed bases containing both.

A paraffin-base crude oil might be refined as follows:

The crude oil is passed through a pipe still into a fractionating tower where the lighter products, as gasoline, kerosene and gas-oil, are taken off and passed to condensers.

The gasoline and kerosene are purified by passage through tanks in which sulfuric acid, caustic soda, plumbite and water washes are variously applied to remove impurities (or their objectionable characteristics), after which the fractions are stored preparatory to blending, further processing, or distribution.

The gas-oil may be treated and stored for distribution as light fuel oil or reprocessed to convert it into gasoline and residual oils. The cracked gasoline is purified and blended with the above-mentioned straight-run gasoline The gasoline as finally distributed may contain, in addition to the above, a casing-head gasoline recovered at the well from natural gas or a natural gasoline which is blended in with the refined products.

Distillation of the remainder is then continued to take off a lubricating or wax distillate which is chilled and filter pressed to remove the wax. The wax is further processed by sweating out the remaining oil, after which it is treated, filtered, and pressed into cakes for distribution. The oil recovered by sweating, together with the chilled oil passing the filter press, are processed in a rerun still and fractionating tower to yield various grades of lubricating oils which are treated, filtered, and stored. These are known as neutral or blending oils.

The residue resulting from the removal of the gasoline, kerosene, gas-oil and wax-distillate, called cylinder stock, contains a wax which is removed by diluting the stock with naptha, chilling and either settling or centrifuging. This wax is made into petrolatum, used chiefly in preparing ointments, salves, and as a rust preventive. The remaining cylinder stock is cleared of the naptha by distilling, is filtered through clay to remove resinous and carbon-forming constituents and is used to make heavy automobile lubricants and steam cylinder oils.

In refining some asphalt-base crudes and mixed base crudes, the lighter oils are usually taken off as in paraffin-base crudes.

The remainder is vacuum distilled to produce lubricating oils of various viscosities, which are treated, filtered, and stored prior to distribution. The final vacuum residue is used for the manufacture of asphalt.

Other variations in processing, depending on the crude oil being refined, may be used, such as the combined fire and steam distillation of high asphalt crudes which, after the removal of the lighter fractions, leaves a flux used as paving asphalt; or the coking distillation of crudes low enough in asphalt to allow good lubricants to be taken off but too high in asphalt for cylinder stock, the final residue being a porous coke.

The chemical treatment of the various products or fractions obtained by physical distillation and crystallization processes is usually applied to remove or change substances contributing undesirable characteristics to the products. The unstable hydrocarbons; sulfur, nitrogen, and oxygen compounds; resins and asphalts; and petroleum acids are responsible for such objectionable characteristics in the final product as bad color, instability of color, bad odor, gumming and corrosion properties, etc. Catalytic treatment has replaced chemical desulfurization in a number of refineries.

Some lighter fractions resulting from noncracking distillation of good crudes may not require acid treatment. In such cases treatment may consist of a caustic soda wash for removal of hydrogen sulfide and some of the mercaptans, etc., or a more complete treatment consisting of the caustic wash followed by the application of a small amount of sulfur together with a plumbite solution for a more complete removal of mercaptans, etc.

Treatment by sulfuric acid is very common, followed by water and alkali washes, and plumbite sweetening. The acid treatment consists of pumping the fraction into a lead-lined, hopper bottom, closed tank (agitator). Sulfuric acid is added while the charge is agitated by air or recirculation. The sludge formed is allowed to settle and is drawn off. For heavier fractions a very small amount of water or strong alkali solution may be added to facilitate the settling operation. A water wash following this is used to remove some of the acidity due to soluble compounds and sludge retained in the fraction. Sludges, resins, sulfonated hydrocarbons, sulfur dioxide, and weak acid solutions are produced.

An alkali wash follows and removes the remaining sulfuric acid and part or all of its acid esters, oil-soluble sulfonic acids, and naphthenic acids persisting from the crude. These are removed largely as soaps and, together with the colloidally suspended solids, contribute largely to the formation of emulsions that accompany alkali washing. Alkali treatment may be applied in the same agitator or, where heavy, viscous, sticky sludges are formed, the alkali treatment may be applied in a separate agitator to avoid redissolving sludge not drawn off.

Continuous acid treatment of light oils is common practice. Acid sludges and waste caustic solutions result.

Raw Materials and Products

Petroleum from all sources may be generally described as consisting of about 83 to 87 percent carbon, 11 to 14 percent hydrogen, and oxygen, nitrogen and sulfur in amounts varying from traces to 2 or 3 percent. There also may be present inorganic constituents remaining as a few hundredths of a percent of ash on combustion. These may be present as oil-soluble salts of petroleum acids, or as salts dissolved in water emulsified in the oil, probably mostly in the latter form as chlorides of calcium, sodium, or magnesium. Nonmetallic elements, such as phosphorus, may occur in organic combinations analogous to that of sulfur.

However, within this narrow range of general composition, a wide variation of product yields is possible due to the amount and distribution of the various homologous series of hydrocarbons composing the raw oil.

In general, the oils show certain characteristics as to composition and specific product yields, depending on the particular locality or field from which they are produced. The particular oil received is routed through a refinery according to its characteristics and economic product yields.

Some of the products and byproducts are:

Products.—Gasoline, kerosene, lubricants, gas oil and fuel oil, wax, asphalt, petroleum coke.

Miscellaneous.—Insulating oils, painter's naphtha, pharmaceutical oils, insecticides, cutting (metal work) oils, petrolatum, etc.

Some typical yields, in percent as listed by Gruse, are shown in table O–1 on page 1178.

TABLE O-1.—*Typical oil product yields for various crude oils as listed by Gruse*

Crude oil	West Virginia	Pennsylvania	Average mid-continent		Muskogee	Mexia-Powell
Method of running	Cylinder	Cylinder	Cylinder	Coke	Flux	Flux
Gasoline and naphtha	38.67	30.59	21.34	21.34	34.92	20.33
Kerosene, etc	18.37	16.94	9.77	9.77	14.29	28.52
Gas oil	17.32	24.12	34.13	53.31	16.47	20.13
Neutral (lubricating oils)	5.96	4.75	5.88	5.88	4.47	5.26
Wax	1.21	1.46	1.88	1.88	.68	.26
Cylinder stock	13.32	14.08	23.50			
Coke				4.32		
Flux					22.46	21.09

EMPLOYEE—RAW MATERIAL RATIO

Information from 38 plants in the Ohio Basin indicates about 30 plant employees per 1,000 barrels (42-gallon barrel) of crude oil refined per day, but the number of employees varied from less than 10 to more than 100 per 1,000 barrels per day.

SOURCES OF WASTE

The chart facing this page, by Weston and Hart, shows the sources of wastes from petroleum refining.

Receiving, transferring and storing of crudes are sources of escaped free and emulsified oils, and water containing organic and inorganic substances in suspension and solution from: Leaks in tanks, piping and appurtenances; cleaning various containers and equipment; draining off water and sediment; and from overflows, spills and boilovers.

Distilling and cracking produce or release organic sulfur and nitrogen comphenols, naphthenic acids, and other compounds.

Treating distillates releases liquors and sludges containing escaped oil fractions pounds, and the products of the chemical treatment.

Storing, loading, and shipping finished products are sources of escaped products and residual products of treatment discharged in or with water draw-offs.

Miscellaneous waters containing oils and solutes may be discharged from gas purification and recovery processes, processes to recover chemical reagents and byproducts. Sludges from water treatment are produced.

QUANTITY OF WASTES

Data from 41 refineries in the Ohio Basin indicate the average volume of waste produced to be about 770 gallons per 42-gallon barrel of crude oil refined. This volume includes cooling waters. Variations of from 100 to 2,000 gallons were found at different refineries.

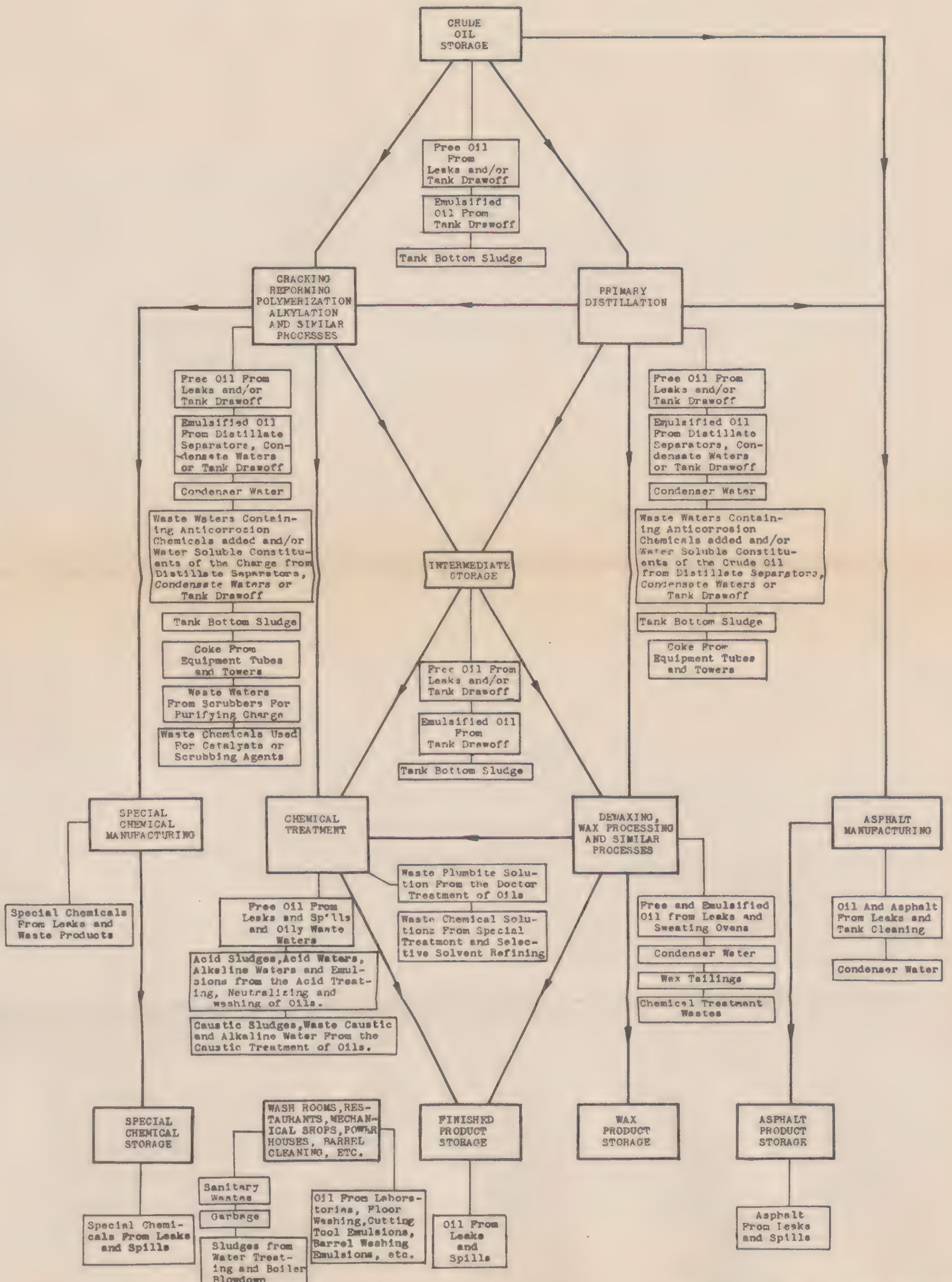
The American Petroleum Institute reports that 80 to 90 percent of the total water used by the average refinery is used for cooling purposes only, never coming into contact with petroleum or petroleum products.

CHARACTER OF WASTES

The combined wastes may contain crude oil and various fractions, and dissolved and suspended mineral and organic compounds discharged in liquors and sludges from the various stages of processing.

Oil may appear as free oil, emulsified oil, and as coating on suspended matter. Ordinarily, waste waters discharged will not contain as much as 0.01 percent (100 parts per million) oil. Floating oil is easily seen, even in very small amounts. On a clean water it has been found experimentally to spread to a thickness of one molecule. The relation of thickness, quantity and appearance has been given as follows:

WASTES OF PETROLEUM REFINING



From "The Water Pollution Abatement Problems of the Petroleum Industry" by R. F. Weston and W. B. Hart, the Atlantic Refining Co., Philadelphia, published in Water Works and Sewerage, May, 1941.

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TABLE O–2.—*Oil film: The relation of thickness, quantity and appearance of floating oil*

Approximate thickness of film	Appearance	Approximate quantity (gallons) oil for a spread of one square mile
0.0000015 inch	Barely visible under most favorable light conditions	25
0.000003 inch	Visible as silvery sheen on surface	50
0.000006 inch	First trace of color may be observed	100
0.000012 inch	Brights bands of color are visible	200
0.000040 inch	Colors begin to turn dull	666
0.000080 inch	Colors are much darker	1,332

Laboratory tests indicated that films up to 0.000003 inch thick did not persist on an agitated water surface for more than 5 hours. Tests at sea where a mixture of oil and sea water was pumped overboard indicated that it took 40 to 100 hours to film out to 0.00004 inch and the oil disappeared from the surface in less than 24 hours after this thickness had been reached.

The disappearance of oils from the surface does not necessarily mean the removal of the oil, however, nor are the above filming-out effects strictly applicable to conditions in the relatively limited areas of rivers where it is possible for light films to accumulate in backwaters and slow-moving threads close to the banks.

The emulsions result from contact and agitation of oil and water in the presence of emulsifying agents. Emulsions such as oil-in-water, water-in-oil, or more complicated types as oil-in-water-in-oil may appear in various draw-offs and treatment process discharges. Emulsions of the water-in-oil type, which will separate and usually float but sometimes settle in water, may occur almost anywhere in the refinery. The milky, highly stable emulsions—water in the continuous phase—are usually limited to wastes from treatment of the heavier oil when caustic washes are used for neutralization followed by a water wash as the final step. Emulsions, in time, become free oil, although they may not so appear locally. The usual refinery gravity separator does not take out the more stable emulsified oils. Discharge of emulsifying agents may result in emulsifying oils otherwise removable.

The oil discharged as coating on suspended matter may blanket the stream with an oily sludge which may persist and continue its objectionable oil effects over a long period of time; it may redeposit following removal by freshets, etc., and, with such agitation, release some of the oil to the surface as floating oil.

Substances other than oils, consisting of true solutes, suspensoids and emulsoids of organic and inorganic nature, are present in the water draw-offs and waste products of treatment.

The American Petroleum Institute has classified these constituents according to the refinery units from which they are released. This classification is reproduced in table O–3 on page 1180.

TABLE O–3.—*Oil refinery waste: Classification of substances found in wastes from the oil refinery industry, as prepared by the American Petroleum Institute*

Refinery unit	Native solutes and those present in end products	Solutes present which result from chemical reactions	Naturally occurring emulsoids and suspensoids, and those persisting in end products	Suspensoids and emulsoids resulting from chemical and physical actions
1. Oil storage	(a) Organic sulfur compounds [1]		(a) Suspended matter in tank bottoms.	
	(b) Acids: H_2S, CO_2, organic acids		(b) Insoluble salts, SiO_2, $Al_2(SiO_3)_3$, S, finely divided substances.	
	(c) Inorganic salts: NaCl, $MgCl_2$, Fe and Al compounds, $CaCl_2$ $(NH_4)_2S$, etc.		(c) Asphaltic compounds (in some cases).	
2. Distillation: A. Straight distillation	(a) Organic nitrogen compounds [2]	(a) Inorganic salts, sulfites, acid sulfites, Na_2CO_3, $(NH_4)_2S$, Na_2S, Sulfates, acid sulfates.	Insoluble organic and inorganic salts, S compounds, sulfonic and naphthenic acids, and insoluble mercaptides.	(a) Oil-water emulsions from steam in towers, etc.
	(b) organic sulfur compounds [1]	(b) Acids and alkalies: H_2S, NaOH, NH_4OH, $Ca(OH)_2$.		(b) Soaps.
	(c) Phenol and like compounds	(c) $(NH_4)_2SO_4$, $(NH_4)_2S$, NH_4Cl		(c) Waxy emulsions.
	(d) Naphthenic acids			(d) Oxides of metals.
B. Cracking and distillation	Same as 2–A	Same as 2–A with the addition of phenols and phenolic compounds.	(a) Suspended coke	Same as 2–A.
			(b) Insoluble salts, FeS, and SiO_2	
3. Treating: A. Sweetening, sulfuric acid, neutralization.	(a) Organic sulfur compounds [1]	(a) Organic sulfur compounds	(a) Suspended matter: PbS, S, S compounds.	(a) Waxy emulsions.
	(b) Organic nitrogen compounds [2]	(b) Phenolic and sulfonate compounds.	(b) Acid and alkaline sludges	(b) Oil-water emulsions.
	(c) Naphthenic acids	(c) Weak H_2SO_4 and other acid solutions.	(c) Polymers and resins	(c) Inorganic salts: PbS, $CaSO_4$, $CaHPO_4$.
	(d) Phenylates	(d) Weak alkaline solutions		(d) Soaps.
		(e) Soaps		(e) Oxides: PbO, Fe_2O_3.
		(f) Inorganic salts: $CaCl_2$, Na_2CO_3, Na_2SO_4, NaCl.		
		(g) Oxides dissolved in alkaline solutions as PbO, CuO, etc.		
B. Clay	Same as 3–A	Same as 3–A, (a), (b), (c), and (f)	(a) Suspended clay earth	(a) Suspended clay, earth.
			(b) Polymers and resins	(b) SiO_2, H_2SiO_3, $Al(OH)_3$.
4. Recovery: A. Gas purification and recovery.	(a) Organic sulfur compounds [1]	(a) Inorganic salts: sulfates, acid sulfates, sulfites, acid sulfites, FeS, $(NH_4)_2S$, Na_2CO_3, Na_2S.	Insoluble S compounds and mercaptides.	Suspended Fe and S compounds.
	(b) Organic nitrogen compounds [2]	(b) Mercaptides		

B. Acid recovery	(a) Sulfonates	(a) Inorganic salts, and H_2SO_4, SO_2, SO_3.	(a) Organic suspensoids: tars	Acid sludges.
	(b) Mineral acids	(b) Organic esters	(b) Some sulfur compounds [3]	
	(c) Organic nitrogen compounds [2]		(c) Some nitrogen compounds [4]	
5. Miscellaneous:				
A. Cooling and boiler water treating.		Inorganic salts: $BaCl_2$, $NaCl$, $NaHCO_3$, Na_2SiO_3, $CaCl_2$, $MgCl_2$, Na_2CO_3, Na_2SO_4, Na_2HPO_4, $CaHPO_4$, etc.		Insoluble and colloidal compounds: $CaCO_3$, $BaCO_3$, $Ca(OH)_2$, $Mg(OH)_2$, $Ba(OH)_2$, $Ca_3(PO_4)_2$.
B. Fire protection		(a) Inorganic salts: $NaHCO_3$, Na_2SO_4, $Al_2(SO_4)_3$.		
		(b) Organic compounds		

[1] Under this caption are included mercaptans, dialkyl sulfides, sulfonates, sulfonic acids, some alkyl and aryl sulfides, etc. Only a few of these compounds will be found in any one type of oil.

[2] Under this caption are included: amines, some amides, quinolines, and pyridines Only a few of these compounds will be found in any one type of oil.

[3] Some alkyl sulfides, thiophenes, etc. Not all of these compounds are found in any one given type of oil.

[4] Quinolines, some amides, pyridines, and some aryl amines. Not all of these compounds are found in any one given type of oil.

NOTE.—Asphalt and lubricating-oil units have not been included in the separate headings. Straight-run distillation involves the heavier oils; also sulfuric-acid treating embraces that of lubricating oils as well as light oils.

There is little information published on analyses and production units from which representative characteristics or unit strength equivalents may be presented. Information secured through private communications relative to tests at one refinery indicated approximate weighted average increases in 5-day biochemical oxygen demand (difference between raw water and wastes) of 46 parts per million prior to corrective measures, 14 parts per million following corrective measures, and 39 parts per million following a change in refining processes.

A 2-day test at a refinery processing 5,200 barrels per day of crude oil and producing 1.366 million gallons per day of wastes, showed the following results: 5-day biochemical oxygen demand, 61 parts per million; suspended solids, 124 parts per million; phenols, 12.8 parts per million; and oil, 150 parts per million. These results indicate sewered population equivalents of about 780 per 1,000 barrels per day based on biochemical oxygen demand, and 1,340 based on suspended solids. The separators at this plant were not functioning effectively, as evidenced by the relatively high oil content of the waste. Consequently the sewered population equivalents may be higher than at plants where the separators are efficient.

Limited data from plants in the Ohio Basin indicate the oil content of refinery waste to be from about 10 to 50 parts per million where efficient separators are in use, and the 5-day biochemical oxygen demand to be less than 50 parts per million. Suspended solids are usually somewhat higher than the biochemical oxygen demand. Most of the oxygen demand occurs during the first day of the 5-day incubation period, indicating that the demand is primarily a chemical one and not due to organic decomposition as in the case of domestic sewage and many industrial wastes.

Phenol content of refinery wastes varies widely since the largest amounts of phenols are in the intermittent wastes. The general average of the continuous wastes appears to be about 10 to 30 parts per million, but when the intermittent wastes are discharged the content may be several hundred parts per million. Oeming's studies of Michigan refineries showed that the spent caustic and spent plumbite solutions, which are discharged periodically in very small volume, contain several thousand parts per million of phenol.

Sewered population equivalent.—From the limited data available on the biochemical oxygen demand and suspended solids of refinery wastes, it is possible to derive approximate sewered population equivalents. These equivalents, per 1,000 barrels of crude oil processed per day, are 600 based on biochemical oxygen demand and 1,200 based on suspended solids. These values may be in error by more than 100 percent and are useful only as a rough indication of the importance, from a standpoint of oxygen depletion, of refinery wastes as compared with other types of pollution. Although the oxygen-depleting character of refinery wastes has caused problems in a number of instances, other effects of the wastes are usually considered more important.

Pollution Effects

WATER SUPPLIES

Surface waters used for domestic water supplies may be made objectionable due to tastes and odors caused by oil and compounds such as phenols, organic sulfur compounds (of which the mercaptans are well known), and complex nitrogenous compounds.

Phenols have produced disagreeable chlorophenol tastes in concentrations as low as 0.001 to 0.02 part per million in the presence of chlorine (as in chlorinated water supplies). The complex organic sulfur group of compounds, chiefly mercaptans, mercaptides, sulfides, disulfides, and polysulfides, produce intense and persistent tastes and odors. Baylis reports that ethyl mercaptan has produced a detectable odor in extremely low concentrations and that naphthenic acids have produced a "smoky-oily" odor in a concentration of 0.01 part per million. These values, although subject to wide variations, show that extremely small amounts of the compounds may be objectionable.

Oil may cause difficulties at water-purification plants by coating filters and other equipment.

AGRICULTURE

Livestock losses have been reported due to refinery waste pollution. Livestock have been reported to develop a taste for crude oil and suffer adverse physiological effects from its ingestion, either because of its laxative properties or its toxicity.

Recreation, waterfowl, aquatic life.—Bathing beaches and dependent facilities may be rendered objectionable and useless by oil deposits on beaches, shores, and equipment. Pleasure-boat owners may object to oil coatings on hulls and equipment and to damage of hull paint. Odors are objectionable in connection with these uses.

Wildfowl die from hunger, exposure, or drowning when disabled through saturation of their feathers by contact with floating oil.

Fish and shellfish are reported to acquire objectionable flavors as a result of refinery waste pollution. The destruction of fish and fish food by oil in minute quantities (absence of any film) is apparently a question of varied opinion; however, oil and water extracts have been found poisonous to brown trout. Prevention of absorption of oxygen from the air by oil films is possibly not serious where surface disturbances can break up the film. Concentration on quiet water might form continuous films.

Other materials which are detrimental to fish life are produced or released in refining processes, and their discharge in excessive concentration may cause death or migration of fish. The effects of some of these compounds have been investigated and a summary of various experimental results on these and other compounds is presented by M. M. Ellis.

As Ellis points out, the application of lethality data to specific pollution problems is impossible because of a number of other factors which have important bearing on the subject:

> Hydrogen sulfide, at 10 parts per million, in tap water caused trout to float on their backs in 15 minutes; lethal dosages (no time reported) were 0.086 part per million for brook trout, 3.8 parts per million for suckers, 4.3 for aquarium goldfish, 6.3 parts per million for carp.
>
> Sulfur dioxide made trout float helpless at 10 parts per million in tap water in 10 minutes, killed orange-spotted sunfish at 16–19 parts per million in tap water in 1 hour.
>
> Phenol killed goldfish at 51 parts per million in distilled water in 1½ to 2⅓ hours, in 72 hours "or less" at 10 parts per million in hard water; 1 part per million was apparently not injurious in 100 hours; trout overturned at 0.4 to 0.6 part per million in 8⅓ hours; and fishes (unnamed) to whom 16.6 to 20 parts per million was lethal, lived at 15 parts per million, but the flesh acquired a phenolic smell.
>
> Naphthenic acids, at 5 parts per million, killed minnows in 72 hours, perch in 16–23 hours, pickerel in 36–48 hours, and at 20 parts per million killed goldfish in 8–16 hours, carp in 26–36 hours.

Excesses of treatment reagents such as sulfuric acid and sodium hydroxide which may be discharged in quantity in spills or intermittent releases may also affect fish life. Sludges may blanket the stream and interfere with spawning.

Miscellaneous.—Fire hazard may result where local conditions are favorable to concentration of floating oils. A serious fire due to accidental ignition of floating oil on a mill pond occurred in St. Louis, Mich., in 1937. New York Bay experiments indicated that an oil of 175° flash point on water at 54° F. could not be ignited by any ordinary means when the thickness did not exceed 0.064 inch (approximately 1,115,000 gallons/square mile). Lighter fractions or dilutions might be ignited more easily.

Remedial Measures

Remedial measures as set forth in the discussion by the American Petroleum Institute, regarding plant practices and waste control methods to minimize pollution, consist briefly of—

(1) Reducing oil escape by—

(*a*) Careful plant practice to prevent leaks, spills, etc.

(*b*) Minimizing emulsion formation, and breaking of emulsions at their source.

(*c*) Removal of the floating oil and floating unstable emulsions, or oil from broken emulsions in separators.

(2) Removal of settleable solids in separators and appurtenant settling basins.

(3) Wastes containing other objectionable pollutional constituents are to to be isolated close to their sources and measures taken either to change their undesirable characteristics or prevent their discharge to receiving waters in objectionable quantities.

RECOVERY

The only product commonly recovered by oil refineries at a profit is oil itself. Some sort of recovery of oil is practically universal practice. This is discussed further in a following section. The Chemical Construction Co. has developed a process for recovering acid from acid refinery sludges and at least one plant of this type is in operation in the Ohio Basin treating the acid sludge from a number of Pennsylvania refineries. Other possible items for recovery are sulfonic acids, aromatic hydrocarbons, and naphthenic acids.

CONTROL OF OIL

The American Petroleum Institute, through its committee on disposal of refinery wastes, has devoted much attention to the proper design, construction, and operation of oil separators, and has published a bulletin (revised 1941) including recommendations for good practice in handling refinery effluents containing oil. Study and experimentation by the committee has led to the development of an improved separator with a number of new features, including two-stage settling; mechanical sludge removal in the first stage; an inlet compartment containing Raschig rings, coarse rock or some other agglomerate to cause film rupture, coalescence and uniform distribution; elimination of the interior baffles which characterized the earlier recommended separator; and improved baffles at the outlet of each settling compartment. Formulas have been developed for determining the dimensions of the various units in terms of the waste flow. It is reported that these new separators, operating under favorable conditions, produce an effluent with as little as 15 parts per million of oil.

Unfortunately, relatively few of the oil refineries have installed adequate separators. Many of those surveyed in connection with the Ohio River Pollution Survey were inadequate in size, constructed of temporary materials, or poorly operated and maintained. The Michigan Stream Control Commission reported in 1938 that a survey of Michigan refinery separator practice indicated a tendency toward makeshift installations of less than minimum capacity and of temporary materials of construction, but that where American Petroleum Institute recommendations had been followed and the installations properly operated, relatively little oil pollution was found.

Where local conditions demand more complete oil removal than can be effected by gravity separators, straw, hay, excelsior, coke, or clay filters appear to be the most practicable treatment devices. Chemical treatment has been tried experimentally with good results, but the costs are reported to be high because of the large volumes requiring treatment.

EMULSIONS

The removal of emulsified oil requires segregation and separate treatment of the portion of the waste containing the emulsion. Processes are available for breaking practically any emulsion found in refinery wastes, but the proper process for use in a particular instance must be determined experimentally since the proper treatment for wastes from a given process may vary with the raw material. The American Petroleum Institute's publication, Disposal of Refinery Wastes, Section I, Waste Water Containing Oil, contains information on the treatment of emulsions.

In addition to wastes containing emulsions, there may be wastes which cause the formation of emulsions in the plant sewers with resulting decrease in the efficiency of the separators. The solution of this difficulty may require the separate treatment of the offending portion of the waste.

CONTROL OF SUBSTANCES OTHER THAN OIL

The control of pollutional constituents other than oil is discussed in detail in the American Petroleum Institute publications on disposal of refinery wastes, by Weston and Hart, and by Black and Klassen. Most of the following is derived from the American Petroleum Institute publications.

Mineral acidity.—The control of anticorrosion activity should be made an important part of the operation of crude-distillation units and rerun stills, so that waste water leaving the operation will be slightly alkaline.

Sulfuric-acid sludges should be handled in closed systems without drainage to plant sewer systems. Use of equipment to accelerate separation of sludge from treated oil to reduce water washing will be beneficial. The Chemical Construction Corporation process for recovery of acid from acid sludges has been mentioned. Sludges may also be burned. Another disposal method consists of

hydrolytic separation of the acid which may be concentrated for reuse; the oil and tar and heavy residue may be burned. Stack gases from sludge burning contain sulfur dioxide and malodorous gases, which may be run through a water scrubber, followed by an oil scrubber, for removal of these materials. The resulting oil effluent may be burned and the acidity of the water effluent neutralized with calcined dolomite. Other acid waters may be similarly neutralized.

Caustic wastes.—With the exception of oil, these are probably the most serious sources of pollution from an oil refinery. In addition to being highly alkaline, these wastes contain large amounts of sulfides, mercaptides and other compounds causing tastes and odors. The biochemical oxygen demand of the wastes is also high.

A number of methods are available for reducing the amount of caustic wastes. These include catalytic desulfurization processes which minimize but do not entirely eliminate the use of caustic soda, two-stage caustic treatment, regeneration of caustic contaminated with mercaptans by steam stripping, and other methods.

Acidification, either by direct application of mineral acid, where economical, or by use of CO_2 and SO_2 in flue gases applied to the wastes, may be used. Weston and Hart report that acidification with mineral acid is not practiced in most cases. With either method the bulk of the liberated phenolic materially usually appears as an oil layer which may be separated and burned. Further reduction of phenol content may be accomplished by extraction with oil. The oils recovered from acid-sludge may be used in oil extraction. The water portion of the separation may be pumped to a cooling tower or spray pond for aeration, dilution, and absorption in those closed systems, or it may be ponded and released during high stream flows. Weston and Hart report that the above method is not practical in most cases.

Another method of waste or spent-caustic and wash water disposal involves a process used in conjunction with litharge recovery. The process is patented (U. S. Patent No. 1,667,550).

Oeming reports that some Michigan refineries dispose of spent caustic by evaporation, using heat generated from burning of the gases evolved in the cracking process. Pennsylvania reports the use of evaporation or neutralization and "hot blowing" of caustic wastes. The successful use of trickling filters for phenol removal at the Dow Chemical Co. plant suggests another possible method of treating phenolic wastes from oil refineries.

Conclusion.—This discussion has been made brief intentionally. It is by no means exhaustive. The complexity of the industry and the need for independent treatment of each waste at or near its source makes the problem of abating pollution by refinery wastes one which requires careful study of each plant. Although this may be said of many industrial wastes, it is particularly true of refinery wastes. The constant change in refinery processes further complicates the problem. Relatively few sanitary engineers have the necessary technical background to deal effectively with all of the problems which arise in dealing with refinery wastes. The problem is primarily one for the technologists of the petroleum industry. The publications of the American Petroleum Institute and the articles by Weston and Hart and by Black and Klassen listed in the Bibliography are valuable sources of information on refinery wastes and their treatment.

Oil Field Wastes

SOURCES OF WASTE

Crude oil in waste waters from producing fields may originate from water draw-offs, apparatus cleaning, and from leaks, breaks, spills, and overflows in connection with pumping, conveying, and storage of oil at the field. Separation of oil from water or brines results in losses of free and emulsified oils.

In abandoned fields the wells are a potential source of escaped oil which may be forced out with brines and water through faulty plugging or capping of wells.

Brine-bearing formations may overlie or underlie oil-bearing formations. Effort is made to close off these sources by plugging such strata and by bottom-plugging or close control of pumping rates to minimize "coning" of underlying brines at the well. However, due to intimate contact of brine and oil in some producing horizons or ineffectiveness of the above, or both, brine is often produced with the oil. The brine and oil are separated by gravity and the brine disposed of.

The brines may reach strata ordinarily carrying fresh water by migrating to these strata in the oil well because of faulty plugging of various porous formations, corroded casings, or improperly sealed shoulders at casing ends.

Where separated brines are ponded, they may reach streams or wells as a result of seepage, leaks, breaks, and overflows. The brines may also be discharged directly to watercourses.

Other wastes: Processing of natural gas and gasoline at the field to produce casing-head gasoline is a source of wastes probably of the nature of refinery wastes.

CHARACTER OF WASTES

The wastes consist of crude oil, suspended matter, and brines of widely varying composition, together with the impurities and products of chemical treatment of casing-head gasoline where the gas is processed.

The escaped oil may consist of free-floating and emulsified crude oil and oil-coated sediment.

The brines consist chiefly of chlorides of sodium, magnesium, and calcium, and not uncommonly sulfates and bicarbonates. Rarer salts, such as iodides and bromides, may appear in small amounts. The specific gravity of brines ordinarily ranges from 1.001 to 1.175, although as high as 1.205 has been found (sea water has a specific gravity of about 1.025).

Tables O-4 and O-5 show some chemical analyses of oil-field brines in Kansas, as reported by Schmidt and Wilhelm.

TABLE O-4.—*Oil-field brines: Mineral analyses of brine samples from selected representative producing areas in Kansas*

Radical	Concentration in parts per million				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Calcium	1,193	1,507	9,800	4,420	12,888
Magnesium	346	428	4,290	2,230	2,510
Sodium	8,260	15,200	63,275	9,325	55,780
Bromide	32	48	633		376
Carbonate	0	0	0	0	0
Bicarbonate	644	339	94	156	43
Sulfate	1,578	966	0	10	457
Chloride	12,750	23,080	127,220	28,600	115,580
Total solids	25,210	44,820	248,600	52,640	210,550

Sample 1: From siliceous limestone at about 3,250-foot depth.
Sample 2: From dolomite horizon at about 3,375-foot depth.
Sample 3: From Kansas City limestone at about 2,600-foot depth (same field as sample 2 but from a different producing horizon).
Sample 4: From the Viola limestone at about 3,350-foot depth.
Sample 5: From producing-sand horizon. This sand found at about 3,200-foot depth.

TABLE O-5.—*Mineral analyses of brine samples from improperly plugged and abandoned wells in Kansas*

Radical	Concentration in parts per million			
	Sample A	Sample B	Sample C	Sample D
Calcium	538	7,440	796	2,200
Magnesium	73	2,125	793	2,212
Sodium and potassium	25,291	43,020	19,800	26,530
Carbonate	1,883	0	0	0
Bicarbonate		81	995	316
Sulfate	3,851	4	932	3
Chloride	34,996	85,765	33,000	51,000
Bromide		252	3.5	209
Iodide		6		4
Total solids		140,460	63,190	83,700

Sample A: Water from 743-foot deep brine well flowing 250 gallons per minute contaminated 4 fresh-water wells in vicinity and increased creek chloride content from 36 parts per million to 72 parts per million. Analyses include silicia, 2 parts per million; iron, 2.4 parts per million; volatile and organic, 1.5 parts per million.
Sample B: From an improperly abandoned well on bank of creek casing stands full of brine and overflows into creek.
Sample C: From flowing brine well drilling operations were shut down at 2,300 feet, well flowed brine through 6-inch casing for many months until drilling operations were resumed, well was finally plugged.
Sample D: From improperly plugged and abandoned well brine flows by heads from gas pressure. Analyses also include 68 parts per million barium.

POLLUTION EFFECTS

Domestic water supplies.—The effect of oils has been discussed under refinery wastes. The brines may increase the chloride content and hardness of receiving waters to an objectionable degree. The United States Public Health Service has recommended 250 parts per million chlorides and 1,000 parts per million total solids as upper limits in the drinking-water standards for interstate carriers. Some municipalities may tolerate higher values for these. Information from the Kansas State Board of Health indicated that when chlorides approach 500 parts per million, a community usually attempts to find a new water supply. The hardness contributed by brine pollution may add considerably to the expense of treatment. A number of municipalities have been forced to develop new sources of water supply because of brine pollution from oil fields.

Livestock.—Actual poisoning by oil-field brines is reported to be rare. The laxative effects are more common, and loss due to prolonged purgative action and other physiological effects of such waste have been reported. Table O-6 shows the toxic doses of NaCl for various animals, as reported by Ferguson, and Table O-7 shows toxic sodium chloride concentrations computed from these doses.

TABLE O-6.—*Oil-field brines: Toxic doses of sodium chloride for various animals as reported by Ferguson*

	Cow	Horse	Pig	Sheep
	Pounds	*Pounds*	*Ounces*	*Ounces*
Toxic dose of NaCl	4–8	2–3	7–8	4½–8
Water consumption:				
Normal, gallons per day	12	10	2	1
Maximum probable gallons per day	25	20	3	2

TABLE O-7.—*Oil-field brines: Toxic sodium chloride concentrations in drinking water for various animals, computed from toxic doses and water consumption*

Animal	Toxic NaCl content in parts per million	
	Normal water consumption	Maximum probable water consumption
Cow	40,000–80,000	19,200–38,400
Horse	24,000–36,000	12,000–18,000
Pig	26,300–30,000	17,500–20,000
Sheep	33,800–60,000	16,900–30,000

Approximately 1 pound of either sodium chloride, sodium sulfate, or magnesium sulfate is considered a purgative for mature cattle.

Vegetation is killed when oil-field brines are allowed to flow for a considerable time over the ground surface, the damage depending on time as well as brine concentration, and composition. Many abandoned leases subjected formerly to the overflow of salt water are now cultivated.

Previously damaged soil may be reclaimed in time by leaching out of various salts by rainfall.

Recreation, fish, wildfowl: The effect of the oil on recreational uses of streams, fish life, and wildfowl has been discussed under refinery wastes. The brines might cause migration of fish to fresher waters.

REMEDIAL MEASURES

Careful operating practices in producing fields such as the proper sealing off of porous strata and casing joints, keeping casings in good repair, and careful maintenance and operation of brine ponds to prevent leaks, breaks, and overflows will help minimize not only the amount of brine produced with the oil but will help prevent brines escaping to other formations or over the surface. Solar evaporation, or evaporation and seepage, are satisfactory in only a few

special instances. Relatively few of the oil-producing areas are in sufficiently arid regions to make solar evaporation very effective, and seepage is usually to be discouraged because of contamination of underground water by brines. Large pond areas are required for this method of disposal.

Evaporation for the recovery of salts has proved practicable in a few instances where the brines contained relatively large amounts of the more valuable halides. It has not been attempted on a large scale and does not hold much promise as a solution of the problem in general.

Storage and regulated release was one of the first methods to be tried for controlling brine pollution, and it remains the standard practice in a number of fields. The shortcomings of this method are numerous. It does not reduce the total amount of brine entering the streams; it requires considerable areas for storage ponds; breaks in the dikes used to form the ponds or accidental spills can cause very damaging surges of brine in the streams; the soil must be relatively impervious to prevent pollution of underground water by seepage from the ponds; careful regulation of the discharge from the ponds must be provided and, if there are a number of disposal systems in a given drainage area, some supervising agency must be provided to regulate the outflow from the disposal ponds in accordance with the ability of the stream to receive the brine without undue pollution.

In spite of these difficulties, regulated discharge of oil-field brines is the most satisfactory disposal method available at present in a number of areas. Much of the success or failure depends on the care and intelligence with which the discharge of brines is regulated.

Underground disposal of oil-field brines is the most satisfactory method from the standpoint of pollution prevention or abatement. Investigations of this method have been carried on for a number of years as a cooperative project by the United States Bureau of Mines and the Kansas State Board of Health, and systems for returning brines to subsurface formations are in successful operation in many States, including Kansas, Oklahoma, Illinois, and Michigan. The Illinois State Health Department requires reinjection of oil-field brines wherever large quantities are produced. Suitable subsurface formations are lacking in some areas, so this method is not universally applicable at present.

Upon release at the surface, the carbonates and iron compounds in the brine are precipitated and must be removed in order to prevent clogging of the formation into which the brine is to be injected. This is usually done by sedimentation and filtration. The cost of conditioning the brine may be considerable.

The cost of an underground brine disposal system in Illinois is reported to be from $15,000 to $20,000, including about $7,000 for drilling, casing, and cementing the well. The remainder of the cost is for the collecting and treating facilities. One system of this type may serve a number of wells.

Underground disposal of oil-field brines is a relatively recent development, and the technique is steadily being improved as its use becomes more widespread. Since it is the most promising of the various methods of brine disposal, it is to be hoped that further experience may extend its applicability to areas where other methods must necessarily be used at the present time.

Separators for preventing the escape of oil are necessary in the oil fields as well as at refineries. Limited data on natural gasoline plants indicate that these are seldom important as sources of pollution. Water is used primarily for cooling. Separators are usually necessary and, if the gasoline is treated chemically, wastes similar to those from the same processes in a refinery will be produced.

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TYPICAL INSPECTION REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–6

INDUSTRIAL WASTES (*Not an actual plant*)

River Mileage Index No. *K 95.6*

Type of Plant: *Oil Refinery.* State: *W. Va.*
Name of Plant: *Smith Oil Co.*
Municipality: *Glen Ferris.* Main Watershed: *Kanawha.*
County: *Fayette.* Subwatershed: *"Direct".*
Address: *18 Shore Rd.*
Source of Information: *A. B. Brown, Supt.*
Plant Operation:
Straight and Cracking Distillation.
168 hrs. per week, 365 days per year.
Average 175 plant employees; 10 office employees.
Maximum 210 plant employees.
Seasonal Variation: *Fairly steady operation.*

(Survey report continued on next page)

Survey by *John Q. Doe.* Date: *10–10–39*

Sewered Population Equivalent Computation:
Factors used *per 1,000 bbls. crude oil processed per day:*
B. O. D.: *600.* Suspended solids: *1,200.*
Sewered population equivalent* based on B. O. D.: *4,200.*
Sewered population equivalent* based on suspended solids: *8,400.*
Remarks --

Computation by *John Jones.* Date: *Oct. 17, 1939.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
*Rounded to nearest two significant figures.

(*Typical inspection report continuation sheet*)

Smith Oil Company, K 95.6
Glen Ferris, W. Va.
Water Supply:
- Drinking water from city—225 g. p. d. ave.
- Industrial and cooling water from Kanawha River—4,500,000 g. p. d. ave. Boiler water treated.

Raw Materials:
- Average 42 gal. bbls. per day:

Crude oil	7, 000
Reclaimed oil (separator)	50
Natural gasoline	360

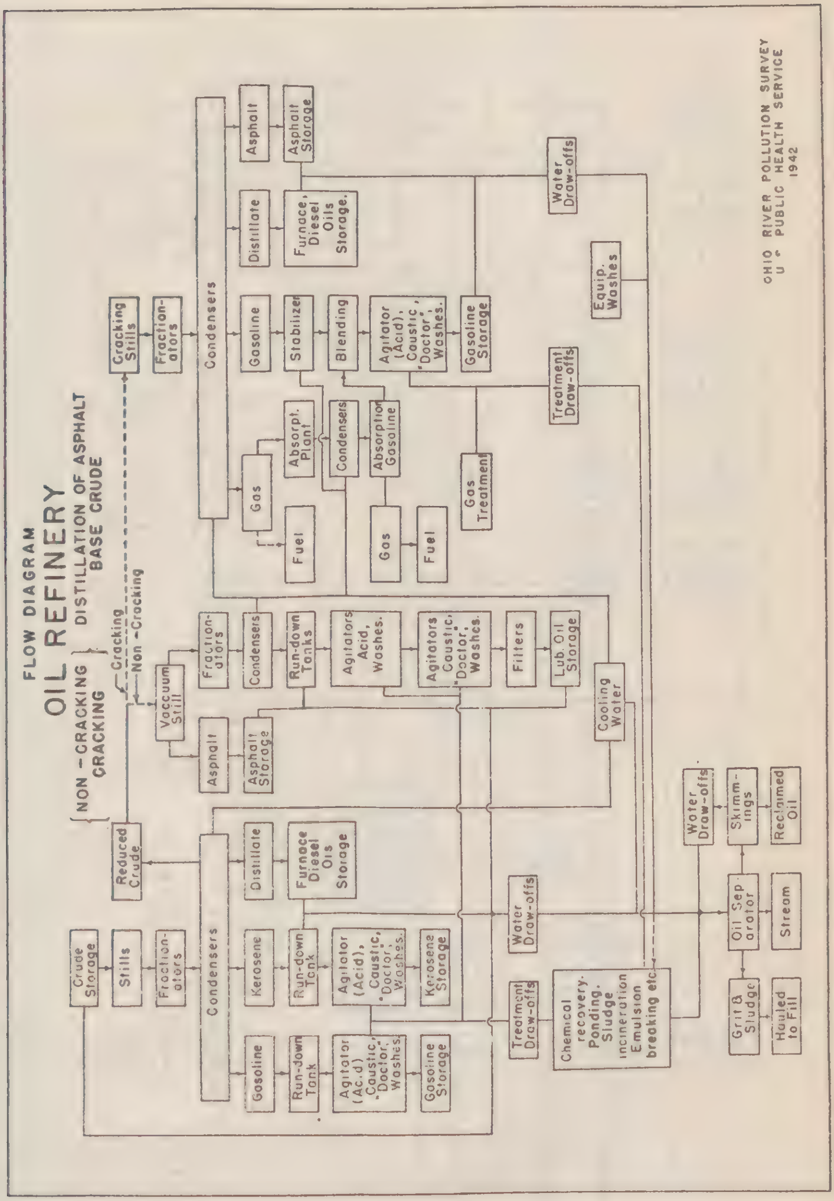
Products:
- Average monthly quantities:

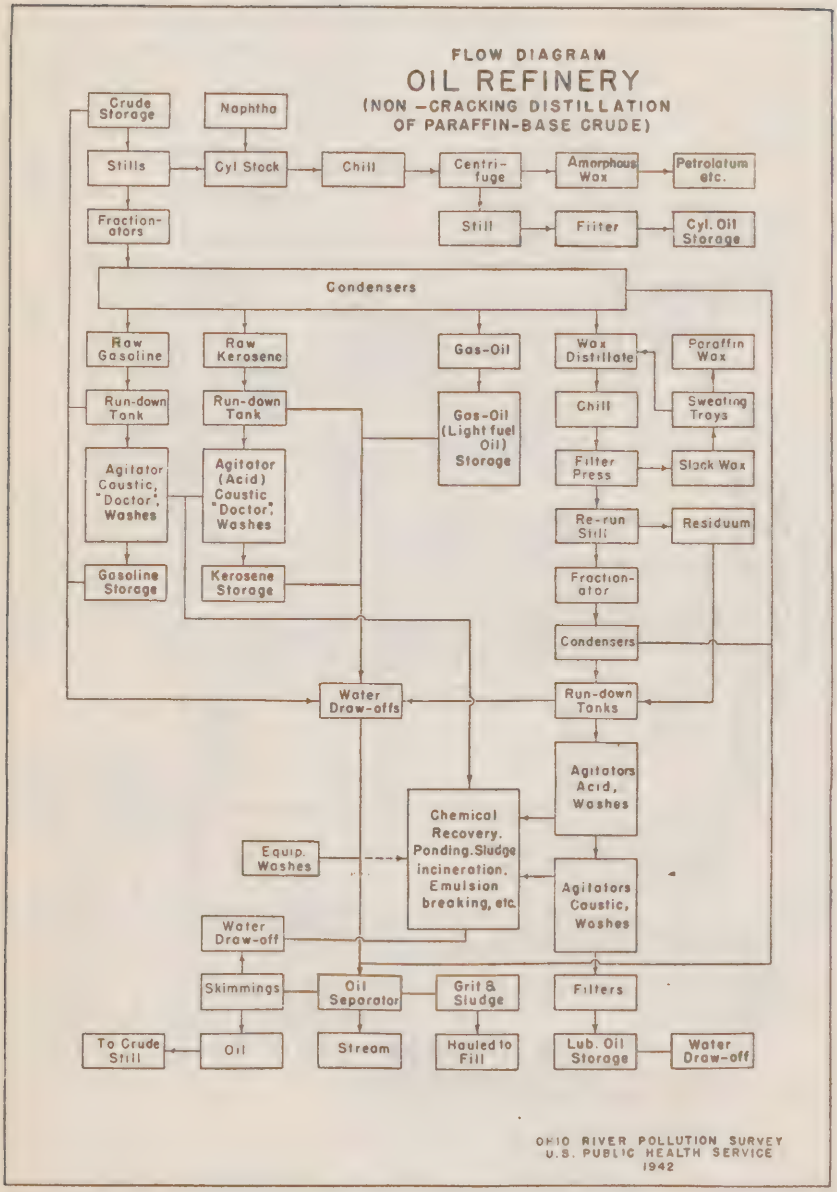
Gasoline	5, 000, 000 gals.
Furnace Oils & Diesel Fuels	29, 000 bbls.
Kerosene	17, 000 bbls.
Industrial Asphalt	29, 000 bbls.
Lubricating Oil	None at present.

Wastes:
- Average 4.5 m. g. d.:
  - Washings—Gasoline and kerosene.
  - Water seal—Small amount.
  - Acid sludge—Removed in tank cars.
  - Alkali—Returned to treatment from ponds.
  - Possible spills—yes, reported to be seldom.
  - Skimming basins—2 bays 70′ x 10′ x 7′ deep.

Outlet:
- 2 8-inch cast iron pipe outlets from skimming basins to river.
- 2 12-inch cast iron pipe outlets for cooling waters.
- Gaging possibilities poor at river (pipes submerged). Can gage skimming basins.

Sanitary Sewage: To city sewers.
Remarks: Floating oil near outfalls—no deposits evident—some taste complaints—maintenance could be improved.


FLOW DIAGRAM
OIL REFINERY
NON-CRACKING
CRACKING
DISTILLATION OF ASPHALT BASE CRUDE
Cracking
Non-Cracking
Crude Storage
Stills
Fraction-ators
Condensers
Kerosene
Run-down Tank
Agitator (Acid), Caustic, "Doctor," Washes.
Kerosene Storage
Gasoline
Gasoline Storage
Distillate
Furnace Diesel Oils Storage
Reduced Crude
Vaccuum Still
Asphalt
Asphalt Storage
Run-down Tanks
Agitators Acid, Washes.
Agitators Caustic, "Doctor," Washes.
Filters
Lub. Oil Storage
Cooling Water
Cracking Stills
Gas
Fuel
Absorpt. Plant
Absorption Gasoline
Stabilizer
Blending
Gas Treatment
Treatment Draw-offs
Water Draw-offs
Equip. Washes
Chemical recovery. Ponding. Sludge incineration Emulsion breaking etc.
Oil Sep-arator
Skimm-ings
Reclaimed Oil
Stream
Grit & Sludge
Hauled to Fill
OHIO RIVER POLLUTION SURVEY
U S PUBLIC HEALTH SERVICE
1942



FLOW DIAGRAM
OIL REFINERY
(NON-CRACKING DISTILLATION
OF PARAFFIN-BASE CRUDE)
Crude Storage
Naphtha
Stills
Cyl Stock
Chill
Centri-fuge
Amorphous Wax
Petrolatum etc.
Fraction-ators
Still
Filter
Cyl. Oil Storage
Condensers
Raw Gasoline
Raw Kerosene
Gas-Oil
Wax Distillate
Paraffin Wax
Run-down Tank
Run-down Tank
Gas-Oil (Light fuel Oil) Storage
Chill
Sweating Trays
Agitator Caustic, "Doctor", Washes
Agitator (Acid) Caustic "Doctor", Washes
Filter Press
Slack Wax
Re-run Still
Residuum
Gasoline Storage
Kerosene Storage
Fraction-ator
Condensers
Water Draw-offs
Run-down Tanks
Agitators Acid, Washes
Chemical Recovery. Ponding. Sludge incineration. Emulsion breaking, etc.
Equip. Washes
Agitators Caustic, Washes
Water Draw-off
Skimmings
Oil Separator
Grit & Sludge
Filters
To Crude Still
Oil
Stream
Hauled to Fill
Lub. Oil Storage
Water Draw-off
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

OIL REFINERY WASTES (Not an Actual Plant)

Plant: Smith Oil Co. State: Va. Ref. No.: K 95.6

City: Glen Ferris County: Fayette Main Watershed: Kanawha

Address: 18 Shore Rd. Sub-watershed: "Direct"

Informant: A. B. Brown Title: Supt. Principal Product: Oil

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	168	365	175
Maximum	—	—	210

Seasonal variation: Fairly steady operation

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking	City	225		
Industrial				
Cooling	River	4,500,000		

RAW MATERIALS:- Crude oil: 7,000 bbls./day average (42 gal./bbl.)

Reclaimed oil: (Separator) 50 bbls./day Other: Nat. gasoline 360 bbls./day ave.

PRODUCTS:- Gasoline: 5,000,000 gal./mo. Fuel: Kerosene 17,000 bbls./mo.

Lub. oil: None at present Other: Indus. Asph. 29,000 bbls./mo.

WASTES:- Quantity: Ave. 4.5 m.g.d. How estimated: Pump ratings

Character:- Washings: Gasoline & Kerosene Acid: Sludge removed in tank cars

Process: Alkali: Returned to treatment from ponds.

Water seal: Small amount Other:

Possible spills: Yes – reported to be seldom.

Skimming basin: 2 Bays 70' x 10' x 7' deep.

Analyses:- Number: Date: By whom:

Appearance:

OUTLET:- Where to: All 4 outlets to Kanawha River.

Description:	Size and Shape	Material	Location	Elevation
1.	2 - 8"	C.I.	Skimming	Basins to River
2.	2 - 12"	C.I.	Cooling	Water to River
3.				

Gaging possibilities: Poor at River (pipes submerged) can gage skimming basins

Conditions below outlet: Color: Some floating oil near outfalls.

Turbidity: Deposits: None evident.

SANITARY SEWAGE: Disposal: To city sewers Persons tributary: 185 average.

REMARKS: Some taste complaints, maintenance could be improved.

Survey by: John Q. Doe Date: 10-10-1939

APPENDIX X OF SUPPLEMENT D

PAPER

AN INDUSTRIAL WASTE GUIDE TO THE PAPER INDUSTRY

CONTENTS

LIST OF TABLES

ABSTRACT

Paper manufacturing divides itself into two steps, pulping and paper making. In a pulp mill the raw material, generally wood, cotton, or linen rags, straw, hemp, esparto, flax, jute, or reclaimed paper, is reduced to fibers and these are refined, sometimes bleached, and dried. At the paper mill various combinations of pulps, loading materials, and finishes are prepared and rolled into sheets to give the final product. Loading materials or fillers generally used are clay, talc, gypsum, precipitated calcium sulfate, or barium sulfate. The more commonly used pulps are ground wood, soda, sulfate or kraft, and sulfite.

The chief liquid wastes from the pulping process of the paper industry are the digester liquors. Other wastes are from sawing, barking, and chipping operations; wash waters; screens, rifflers, knotters, and thickeners; and bleach and bleach washes. Paper making process wastes come mainly from the beaters, regulating and mixing boxes, and paper machines. Fiber losses in paper making may vary from 0.1 to as high as 20 percent, generally averaging around 3 percent. Number of employees, approximate flows, sewered population equivalents, and typical analyses for pulp and paper mills are shown in table P-1.

TABLE P-1.—*Number of employees, waste flows, sewered population equivalents, and typical analyses for pulp and paper mills*

Product	Number of employees	Wastes in gallons	Sewered population equivalent: Biochemical oxygen demand	Sewered population equivalent: Suspended solids	Typical analyses: Biochemical oxygen demand	Typical analyses: Suspended solids
	Per ton of product daily				Parts per million	
Pulp mills:						
Ground wood	250	5,000	16	----------	645	----------
Soda	300	85,000	460	6,100	110	1,720
Sulfate (kraft)	----------	64,000	390	----------	123	----------
Sulfite	310	60,000	1,330	----------	443	----------
Miscellaneous paper—no bleach	440	39,000	26	520	19	452
Miscellaneous paper—with bleach	460	47,000	40	220	24	156
Paperboard	210	14,000	97	445	121	660
Strawboard	140	26,000	1,230	1,920	965	1,790
De-inking used paper	----------	83,000	1,250	----------	300	----------

Remedial measures may consist of byproduct recovery, waste treatment, or a combination of both. Bark and sawdust at pulp mills are recovered by screening, flotation, or sedimentation and then dried and incinerated for heat recovery. Bark chips may be leached and, after washing and grinding, be mixed with kraft paper to form laminated pressboard. Fiber is recovered from washers and thickeners by save-alls. Sulfate process black liquors are processed for recovery of chemicals and heat.

Sulfite black liquor presents the greatest pollution problem in the paper and pulp industry. It may be treated either by the Howard process, a three-stage precipitation method using a caustic lime reagent or by the Paulson process, utilizing multistate evaporation. Neither of these processes has proven to be entirely satisfactory. Although a high biochemical oxygen demand reduction has been claimed for the Howard process, an actual installation has shown a maximum reduction of only about 45 percent. Byproducts suggested by other investigations include adhesives, fertilizers, alcohol, tanning liquor, dye bases, and road binders. Studies have been made on the purification of mixtures of sewage and sulfite waste liquors by the activated sludge method. Satisfactory results were obtained with sewages containing up to 6 percent of Howard process effluent and up to 10 percent of raw calcium-base sulfite liquor.

Chemical precipitation, ponding, filtration, and aeration have also been applied to the treatment of paper mill wastes with varying degrees of success.

Description of Process

Paper consists basically of cellulose fibers formed or matted into a sheet. The choice of pulp loading and finishing materials is limited by the particular use for which the product is intended. The process divides itself into two steps, pulping and paper making, and a complete plant may include either or both of these steps. In a pulp mill the raw material is reduced to fibers and these are refined, perhaps bleached, and dried. At the paper mill various combinations of pulps, loading materials, and finishes are prepared and rolled into sheets to give the final product.

PULPING PROCESSES

Raw materials are reduced to fibrous pulp by mechanical or chemical means. When wood is used in either case, it is sawed to size and barked.

Ground wood pulp.—Mechanical or ground-wood pulp is prepared by grinding the wood on sandstone or emery wheels, from which it is water carried through screens. This pulp contains lignin and resinous matter which discolors it in the light. The fibers are short and do not mat well together. It is generally used for making cheaper grades of papers, such as newspaper, and in combination with other pulps.

Chemical pulps.—Chemical pulps are usually prepared by the soda, sulfate, or kraft, or the sulfite process. In all of these the wood is reduced to chips and screened to remove dust. The principal differences in their manufacture are in the method of digestion and in the chemicals used. These are as follows:

Soda pulp is generally made with soft woods such as poplar, cottonwood, and basswood. The digester is loaded with 3 to 5 cords of chips; a caustic soda solution, produced by treating soda ash with lime, is run in and the charge boiled for 8 to 10 hours under steam pressure. Noncellulose matters, such as lignin and resins which are made up largely of organic acids, are decomposed or combined with the soda. The fiber is also attacked by the alkali, resulting in a weak fiber.

Sulfate or kraft pulp is made using coniferous wood chips which are boiled from 4 to 7 hours with sodium sulfide, hydroxide, sulfate, and carbonate. The first two of these chemicals are active in the disintegration. The sulfide is reduced by the reduction of sodium sulfate and the hot alkali sulfide dissolves the lignin and other noncellulose matter, leaving a very strong fiber.

Sulfite pulp is made with coniferous wood chips which are placed in a closed vessel, or digester, and treated with a solution of calcium bisulphite under a pressure of about 70 pounds and a temperature of 325° F. There are two cooking methods, in general use, the Mitcherlich, or slow cook, method and the Ritter-Kellner, or quick cook, method. In the Mitcherlich process heating is done by passing steam through coils placed inside the digester. The conventional heating process for the quick-cook digester has been to blow the steam directly into the vessel. In up-to-date practice, however, the heating is done indirectly by means of heat exchangers placed outside the cooker and the cooking acid made to circulate from the top of the digester, through the heat exchanger, and into the

bottom of the digester, or vice versa. The chief advantages are that no dilution of the cooking acid takes place, thus allowing the cooking process to be done at a lower temperature, the pulp quality is better, and a higher yield is obtained.

Following digestion by one of the various methods described, wood pulps are blown into a closed blow pit where the black liquor is drained off to waste or recovery. The drained pulp is washed either in the pit or in a wash tank, although some plants drain and wash in the digester. The wash waters may then be wasted, stored and reused, or sent through a recovery process. The unbleached fibers, together with impurities, knots, clumps, and undisintegrated matters are further processed as follows:

Screen, riffler, knotter.—After digestion and washing, the pulp is stored in a large stock chest from which it flows at a uniform rate through one or more of these devices. Knots and other disintegrated matter are removed, some of this material being returned to the pulp stream after passing through a Jordan, or refining machine.

Thickener.—The pulp is partially dewatered by passage through the decker, a cylindrical screen revolving across the pulp stream. This picks up the pulp from the screen and passes it to the bleach.

Bleaching.—The thickened pulp is agitated in a weak solution of calcium hypochlorite, which is either heated or has acid added to it to speed up the reaction. A thorough washing follows. Sulfate pulps are difficult to bleach and generally find best use in the manufacture of strong brown wrapping papers. The bleached pulp is dried and marketed or passed on wet to the paper mill.

PAPER MAKING

Wood pulps, produced either mechanically or chemically, are used in combination with rags, straw, hemp, esparto, flax, jute, and reclaimed paper as raw materials. The steps involved in the preparation of the material for the paper machine are as follows:

Beaters.—The pulp or combination of pulps, together with the fillers, sizing, and dyes are disintegrated and mixed in the beater, or Hollander. The filler which may be clay, talc, gypsum, precipitated calcium sulfate, or barium sulfate, is added to improve the surface of the paper and to increase its opacity. The sizing may be any one of various glutinous materials and is used to fill the pores. In this machine the materials pass under a rotating cylinder equipped with dull knives which beat or break up the bunched fibers and through repeated cycles effect a thorough mixing of the constituents. Washing of pulps prior to mixing is sometimes done in the beater by the use of an appurtenant revolving screen.

Refiners.—The pulp mixture pasess through a Jordan, consisting of a tapered knife-equipped cylinder rotating within a close fitting casing in which knives are embedded. This apparatus cuts the fibers to the size desired.

Stuff chest, regulating box, mixing box.—These devices are used for storing the pulp, regulating the water content of the mixture, and mixing to insure uniform consistency, respectively.

Screen.—Lumps and slime spots are removed from the pulp mixture by passing it through a vibrating tank in which a revolving screen intercepts these impurities.

PAPER MACHINE

After preparation, the pulp is evenly distributed across a traveling belt of fine screening, or Fourdrinier wire, and carried to the rolls. The water contained in the prepared pulp is called white water. A part of this is lost in the Fourdrinier wire. A screen roll, or dandy, lightly eliminates inequalities at the end of the wire travel, a suction roll removes more white water, the sheet is passed through press and drying rolls, and finally to the finishing rolls, or calender, after which it is wound on reels.

STRAWBOARD

In the manufacture of strawboard, straw and lime are placed in a closed vessel and subjected to cooking with steam under a 40-pound pressure for 12 hours. The resultant stock of softened woody fiber is allowed to drain for 24 hours and then run through washers to remove the lime. As it comes from the washers, the material is run into vats, where it is mixed with large quantities of water and passed over hollow cylinders having fine wire-cloth surfaces which allow the water to escape. The fiber is then taken by woolen felts that are pressed down on the surface of the cylinder, making a web of paper on the felt. The pulp is next carried simultaneously over and under a double train of steam-heated hot

rolls. As it passes through the train it is constantly pressed and dried, and finally separated from the cloth support. It then goes to the trimming machine and is cut into sheets of proper size. Just before trimming the board may be coated on one or both sides with a thin paper facing or finish.

Raw Materials and Products

Although considerable difference exists in the ratio of raw material to product yield for individual plants it is possible, in the case of pulp mills, to arrive at some general relationships between them. These general relationships are given in table P–2.

Table P–2.—*Relationship of raw materials, pulp and strawboard mills*

Raw materials	Unit per ton product	Dry pulp				Straw-board
		Ground-wood	Soda	Sulfate (kraft)	Sulfite	
Wood	Cord	1.0			2	
	Ton		2.0	2.4		
Straw	Pound					2,800
Lime	Pound		500	325	[1] 175	180
Limestone	Pound				[1] 350	
Sulfur	Pound				250	
Soda ash	Pound		250			
Sodium sulfate (salt cake)	Pound			450		

[1] Applied either as lime or limestone.

Due to the great variability of raw materials and final products in paper manufacturing, it is difficult to show even general relationships between them. Some of the principal papers manufactured are as follows:

Printing papers.—These contain large amounts of loading materials and are generally made from wood pulps.

Newspaper.—This is made chiefly from a mixture of mechanical and unbleached sulfite pulps.

Wrapping papers.—They are made from straw, jute, hemp, old rope, and colored rags. Sulfate pulp gives a particular strong wrapping paper. This product is sized and sometimes calendered but seldom bleached.

Writing papers.—The best materials, generally wood pulps, with or without rags are used for these. They are highly sized and carefully calendered.

Blotting and tissue papers.—Both of these are unsized and unfilled. Blotting paper is loosely felted and thick. Tissue papers are made from long fibers, principally hemp and cotton.

Parchment paper.—Unsized paper is treated with sulfuric acid and glycerin, after which it is washed, treated with dilute ammonia, and given a final wash.

Impervious wrapping paper.—This is produced by a long continued beating of pulp or rags in the Hollander until all fibers are broken down into a gelatinous mass. When run through the paper machine a thin transparent paper results. Its chief use is for wrapping butter, confectionery, and other food products.

Table P–3, showing ratios of employees to products for paper mills, is based mainly on plants in the Ohio River Basin.

Table P–3.—*Ratio of employees to products*

Product	Number of employees [1]	Product	Number of employees [1]
Pulp mills:		Miscellaneous paper:	
Groundwood	250	No bleaching	440
Soda	300	With bleaching	460
Sulfate		Paperboard	210
Sulfite	310	Strawboard	140

[1] Per 100 tons of products per day.

Sources and Quantity of Wastes

The chief sources of wastes in the pulp industry are the digester liquors. Other wastes are from barking, and chipping operations; screens, rifflers, knotters, and thickeners; and bleach and bleach washes.

At paper mills most of the wastes are from the beaters, regulating and mixing boxes, screens, and paper machines. The average quantities of wastes which may be expected from pulp and paper mills are shown in table P-4. Paper mill water consumption and fiber loss quantities represent conditions found prior to concentrated pollution control measures.

Table P-4.—*Average waste discharges per ton of product*

Product	Gallons of waste [1]	Product	Gallons of waste [1]
Pulp mills:		Miscellaneous paper:	
Groundwood	5,000	No bleaching	39,000
Soda	85,000	With bleaching	47,000
Sulfate (kraft)	64,000	Paperboard	14,000
Sulfite	60,000	Strawboard	26,000
		Deinking—old paper stock	83,000

[1] Per ton of product daily.

Fiber losses in paper mills may vary from 0.1 to 20 percent, generally averaging around 3 percent. Where bleaching is done it has been found that unit waste volumes are larger but, due to the efficiency of rotary filters used as bleach washers and to the reuse of white water, the fiber losses are reduced. The bleaching operation removes additional organic solids from the pulp, resulting in an increased oxygen demand of such wastes.

Character of Wastes

PULPING PROCESS WASTES

The character of the various wastes from pulping operations is as follows:

Sawing, barking, and chipping.—Bark press and wood wash wastes contain suspended wood matter which, if discharged directly to the stream, may contribute turbidity and possible deposits.

Digester liquors.—These are the most objectionable wastes produced in any appreciable quantity in the pulping process. The black liquors contain intercellular substances of the wood and excess chemicals used. Sulfite digester liquor, for example, contains about 48 percent of the wood used, has a high immediate chemical oxygen demand due to the presence of such compounds as sulfur dioxide, has a high biochemical oxygen demand, and contributes color. It may impart an acidic condition and introduce compounds of a toxic character, such as lignin salts, which may be harmful to aquatic life. Sulfate digestion sometimes forms small quantities of mercaptans. These have a disagreeable odor and are reported to be toxic to fish life in concentrations of more than 1 part per million. In Michigan it is reported that from 10 to 15 percent of the sulfate black liquor is lost in the final washing of the pulp. Occasions are said to have arisen where the flesh of fish has become tainted due to absorption of these odors.

Wash waters.—These are used following draining of the pulp in the blow pit and are generally dilute liquors of a character similar to the black liquors. Escaped fiber may also be present in this waste. Some plants store and reuse these waters as subsequent washes and pass them, when too concentrated for wash use, through the recovery process along with black liquor.

Screens, rifflers, knotters, and thickeners.—Coarse undisintegrated material. knots, granular impurities, and fiber make up this waste. Some of these substances may be recovered and reprocessed.

Bleach wastes.—These contain fine fiber and excess calcium hypochlorite bleach. Bleaching releases additional organic material from the pulp and adds to the oxygen loads of the wastes. The lime sludge formed, if discharged as waste, will add alkalinity and possibly calcareous deposits to the stream.

Recovery process wastes.—Certain residual wastes remain even when recovery is practiced. These consist mostly of dumped sludges as well as leakages and spills of black liquors.

PAPER-MILL WASTES

In general, the bulk of the oxygen requirement for paper-mill wastes comes from dissolved organic substances. Although fiber exerts a slow oxygen demand, its deposition in stream beds may prevent growth of normal vegetation. In addition, these deposits may rise to the surface during decomposition and cause nuisances. The character of the specific wastes in paper manufacturing is as follows:

Beater wastes.—Water used to wash raw stock will discharge wastes containing dirt, fiber, and clay. Raw stock fiber loss may amount to 1 percent of the production, while waste materials in reclaimed-paper washes may be 25 percent of the weight of old paper treated.

Regulating and mixing box.—The consistency of the pulp is regulated by diluting or dewatering, and wastes, or white water, from this source may carry lost fiber and filling materials. This results in turbidity and settlement effects in the stream, as well as additional oxygen requirements.

Screens.—The removal of fiber clumps may be accompanied by refining and return to the system. Discharge to the stream adds to the depositing possibilities.

Paper machine.—White waters containing fiber and filling materials are discharged from the vacuum rolls. These wastes may contain up to 45 percent of the clay used and 5 percent of the fiber produced.

STRAWBOARD WASTES

The most concentrated and polluting waste in the manufacture of strawboard paper comes from the beaters where the straw is washed after digestion. It contains lime, dirt or silica, and organic matter. The machine waste, which also includes the felt wash, is less concentrated and contains mostly fiber.

Table P–5 shows typical analytical results and sewered population equivalents for pulp and paper-mill wastes.

TABLE P–5.—*Sewered population equivalents and typical analytical results*

Product	Sewered population equivalent (per ton of product)		Typical analytical results (parts per million)	
	Biochemical oxygen demand	Suspended solids	Biochemical oxygen demand	Suspended solids
Pulp mills:				
Groundwood	16	----------	645	----------
Soda	460	6,100	110	1,720
Sulfate (kraft)	390	----------	123	----------
Sulfite	1,330	----------	443	----------
Miscellaneous paper:				
No bleach	26	520	19	452
With bleach	40	220	24	156
Paperboard	97	445	121	660
Strawboard	1,230	1,920	965	1,790
De-inking—used paper	1,250	----------	300	----------

Where bleaching is done the increase in equivalents is due to the additional organic matter released from the pulp by the bleach. Combination pulp and paper mills will, in general, have lowered sewer population equivalents on a ton-production basis than the pulp mills. This is due to differences in weight of final product caused by the addition of loading materials and to the use of purchased pulps for mixtures required in certain papers.

POPULATION EFFECTS

The principal effect of pulp and paper wastes is one of deoxygenation due to organic oxygen demand of the waste. Where fiber losses are high deposits are created. Color is also an objection. In general, wastes from pulping processes are more objectionable than wastes from paper machines.

Probably the greatest stream-pollution problem in connection with pulp and paper mills is presented by the discharge of waste sulfite liquor. A large part of this waste is carbonaceous and suffers decomposition by bacterial action. The solids also create heavy sludge deposits, forming a mat over the stream bottom and smothering the aquatic plant life. Depletion of the dissolved oxygen will

also affect fish life, causing either migration or death by suffocation. Experiments have shown that while sulfite waste liquor dilutions of 1 to 500 were irritating to fish, definite toxic effects occurred mainly in dilutions of 1 to 200 or less. However, since these wastes would probably deplete the dissolved oxygen in a stream below the critical amount necessary to sustain fish life before the limiting dilutions are encountered, the most significant characteristic from the pollution standpoint is the oxygen demand. Development of Sphaerotilus locally referred to as "slime" causing clogging of nets, screens, etc., is reported below one sulfite mill despite a high dilution of the waste.

Remedial Measures

The treatment of pulp and paper-mill wastes and possible economical byproduct recovery have been the object of much research. Some of the results have led to actual plant use. However, certain problems, particularly having to do with sulfite pulp and strawboard waste disposal have not been satisfactorily solved and continued research is needed.

PREPARATION OF WOOD FOR PULPING

Bark and sawdust at pulp mills may be recovered by screening, flotation, or sedimentation and then dried and incinerated for heat recovery. Bark chips may be leached and, after washing and grinding, be mixed with kraft paper to form laminated press board.

SODA AND SULFATE PULP

Soda and sulfate black liquors are processed for recovery of chemicals and heat. These liquors are evaporated, burned in a rotary furnace, leached, causticized with lime, diluted with raw black liquor, and stored for reuse in the digester. New lime is used to replace that lost and soda ash or salt cake is added for the soda or sulfate process, respectively. The two chief byproducts of these recovery processes are carbon and calcium carbonate sludge. The carbon residue is activated or otherwise prepared and marketed under various trade names, important uses being as a decolorizing agent, lamp-black adulterant, and in the case hardening of steel. Lime sludge from causticization is burned and either reused to causticize more liquor or is marketed as agricultural lime or whiting. At some plants the carbonate is used as a loading material. Black liquor wash waters from the blow pits are sometimes run through the above process when too concentrated for reuse as primary washes.

SULFITE PULP

Sulfite black liquor has been the subject of extensive research aimed at accomplishing an economic recovery. One method for the treatment and recovery of waste sulfite liquor which has received much attention is the Howard process now in use at one mill. The method is essentially a three-stage precipitation process, using a caustic lime reagent. The screened raw liquor is mixed with sludge from the third settling tank, treated with lime, and settled. The effluent goes through secondary and tertiary precipitation and settling, using lime in each case. Primary sludge is recovered to make cooking acid; secondary sludge is vacuum filtered, the cake being used for fuel and the filtrate returned to the process; and the tertiary sludge is mixed with incoming raw liquor prior to primary reaction and settling, the filtrate being run through a heat exchanger to recover heat for use in heating water for bleaching. It is claimed that the liquors processed contain 90 to 95 percent of the organic matter dissolved in the digesters and that the total biochemical oxygen demand reduction will be over 80 percent. Studies of the actual installation at a Wisconsin paper mill have shown a biochemical oxygen demand reduction of 45 percent to be the best obtainable from the process. The results obtained depended to some extent on the types of wood and the cooking procedures used.

The Paulson process involves evaporation and utilization of sulfite liquor as a fuel. A double-effect evaporator is used and heat is recovered for preheating the sulfite liquor and for cooking in the digesters. The effluent sirup will contain 50 to 55 percent solids and can be burned in liquid form under the boilers. No results of actual performance on a plant scale are available as no commercial installations are known to exist. However, the process has been reviewed by several investigators and all have agreed that it is feasible and practical.

Byproducts suggested by other studies include adhesives, fertilizers, alcohol, tanning liquor, dye bases, road binder, binder for briquetting hard coal dust, and core binder. The use of these various processes is at present limited by the expense of treatment and a limited market for the absorption of the byproducts.

In experiments on the purification of mixtures of sewage and sulfite waste liquors by the activated sludge method, satisfactory results were obtained with sewages containing up to 6 percent of Howard process effluent and up to 10 percent of raw calcium-base sulfite liquor. Higher percentages produced sludges too heavy to be kept in suspension by normal aeration, due to the precipitation of calcium carbonate. A magnesium-base sulfite liquor produced bulking sludges. The importance of adding nitrogen and phosphorus in assimilable form to dilution waters used for determining the biochemical oxygen demand of mixtures containing high proportions of sulfite wastes was shown. It is reported that failure to add these necessary nutrients accounts for the claims of high biochemical oxygen demand removals of the Howard process.

The use of save-all devices and closed water systems in pulp mills is in general governed by the economic value of the practice to the manufacturer. Under these circumstances treatment may be practiced up to the point of maximum economic recovery. In many cases this may be far from satisfactory from a pollution elimination standpoint.

PAPER AND BOARD MILLS

A review of actual practice in the treatment and disposal of paper and board mill wastes shows the methods of correction, in general, to be as follows:

Save-alls, recirculation.—Screens, vacuum filters, flotation and sedimentation devices, and recirculation with or without save-all clarification are common for machine wastes. At three Pennsylvania board mills save-all with recirculation in a partially closed system effected biochemical oxygen demand reductions varying from 39 to 85 percent while at three other mills having closed systems and sedimentation of weekly or other intermittent wastes gave biochemical oxygen demand reductions of 90 percent. For other plants using save-alls and a partially closed system, reductions were reported as 64 percent at a fine paper mill, 50 percent at a tissue mill, and 79 percent for a towel mill. In general, these practices can be applied with high overall efficiencies to board mills, where suspended matter can ordinarily be returned to the product, and to paper mills working on clean raw material such as wood pulp, paper shavings, and clean rag stock or pulp. Costs of recirculation systems are subject to considerable variation but a figure in the order of magnitude of $5,000 per machine is typical. Savings in water and material will result. In the case of plants having color change complications recirculation and recovery as commonly applied effect a machine waste correction only.

Chemical precipitation.—This method has been applied to the various wastes. A Michigan mill making tarboard automobile strips on a wet machine and boxboard, wrappers, asbestos board, and similar products on a dry machine treats these wastes separately and returns the sludge to the respective processes. Biochemical oxygen demand reductions of about 64 percent were obtained in each case. At an Indiana mill manufacturing grease proof, glassine, and manifold paper from sulfite pulp treats all wastes with alum in the first of three ponds in series. The sludge is dried on beds and the effluent from the third pond is recirculated to the process. Estimated costs of chemical precipitation are shown on table P–6.

TABLE P–6.—*Estimated cost of chemical precipitation*

Mill production per day		Waste flow, million gallons per day	Total installation cost	Daily operation and maintenance
Paper	Board			
25 tons	50 tons	0.5	$30,000	$19
50 tons	100 tons	1.0	45,000	33
100 tons	200 tons	2.0	70,000	60
150 tons	300 tons	5.0	155,000	143

Ponding.—An Ohio mill producing paperboard from wood pulp, paper shavings, and old newspapers discharges its beater wastes to a seepage pond. Another Ohio mill with similar raw materials and products provides ponding for 10 percent of the machine wastes and multiple sedimentation for the remaining 90

percent. About 80 percent of the waste water is recirculated. A large Pennsylvania pulp and paper mill has provided for its deinking wastes a reservoir having a capacity 60 times the daily discharge of these wastes plus wash waters from the used paper department. The pond effluent is aerated in cascading 1.4 miles down a steep channel to the river. The over-all reduction in biochennical oxygen demand is about 77 percent.

Filtration.—No installations of this type are known to be in present use. Two Massachusetts paper mills formerly used this method of treatment but it was later discontinued. One of the mills produced manila and other papers from rope, bagging, and wood pulp. Machine wastes were recirculated to the washers, while cinder filters received all the settled washer waste and as much of the settled beater waste as they would take. Rotary liquor was discharged either on the drying sludge or on to the cinder filters, resulting in a lowering of their efficiency. The other mill produced heavy paper boxes, shipping cases, cartridge cases, and similar items from cotton and hemp stock. Machine wastes were settled with alum by fill and draw operation, with a return of sludge to the process and the discharge of the effluent to the stream. Boiler liquors were discharged to waste land while washer wastes were treated by plain sedimentation and sand filtration.

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Typical Inspection Report

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–8

INDUSTRIAL WASTES (*Not an actual plant*)

River Mileage Index No. *CP–217.5*

Type of Plant: *Pulp Mill.* State: *Ohio.*
Name of Plant: *Burden Pulp Co.*
Municipality: *Fair City.* Main Watershed: *Chase River.*
County: *Weaver.* Subwatershed: *Perry Creek.*
Address: *600 Main Street.*
Source of Information: *A. B. Chester, Gen. Sup't.*
Plant Operation:

100 hours/week—300 days/year.
Average 200 plant employees.

Seasonal Variation: *None.*

(Survey report continued on next page)

Survey by *D. E. Fowler.* Date: *5–17–39*

Sewered Population Equivalent Computation:
Factors used *per ton of pulp produced daily:*
B. O. D.: *1,330.* Suspended solids: *Not available.*

Sewered population equivalent* based on B. O. D.: *93,000.*
Sewered population equivalent* based on suspended solids ______.

Remarks: *P. E. based upon normal daily productions.*
Computation by *G. H. Innes.* Date: *1/10/40.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant of the factors used becomes available.
*Rounded to nearest two significant figures.

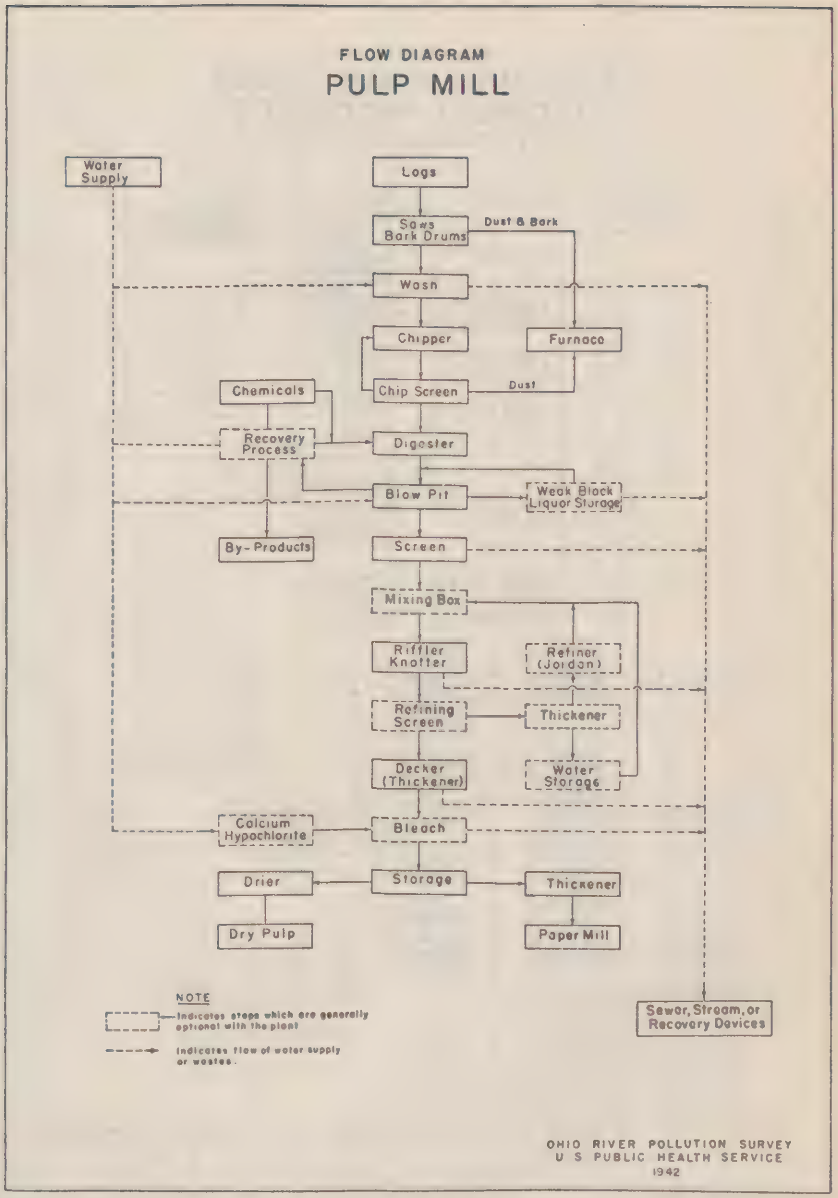
(*Typical inspection report continuation sheet*)

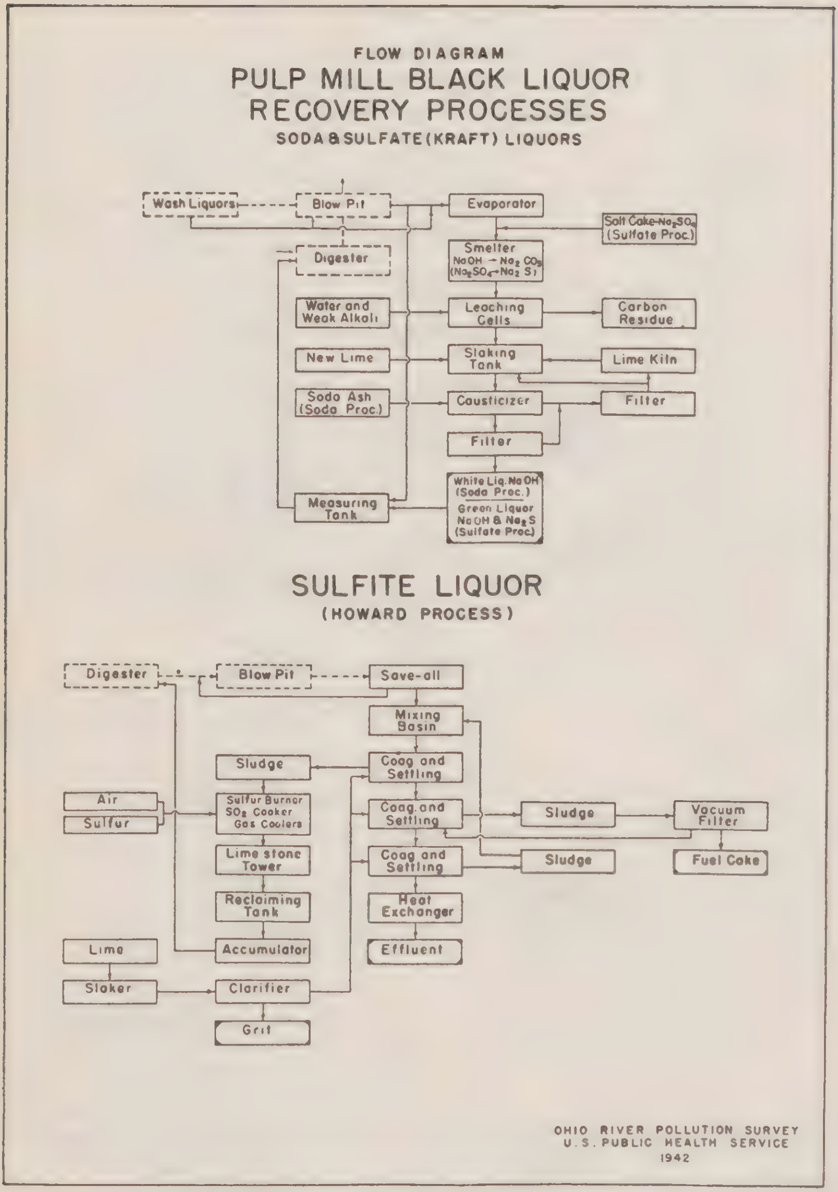
Burden Pulp Co.,
Fair City, Ohio. CP–217.5

Water Supply:

	Average	Source	Treatment
Drinking and industrial	3.5 million gallons per day.	City	None.
Cooling	No estimate	Creek	None.

Raw Materials—Per day:
Spruce wood—140 cords.
Sulfur—17,500 pounds.
Limestone—21,000 pounds.
Bleaching powder—28,000 pounds.
Products—Sulfite pulp:
Production capacity—80 tons/day.
Normal production—70 tons/day.
Average: 3.5 M. G. D. plus cooling water—2.0 M. G. D. washings and 1.5 M. G. D. of process wastes. Estimates based upon meter records. Wastes are discharged through a fine screen save-all. Bark and sawdust are burned and the ashes used for fill. The plant effluent had a turbid appearance.
No analyses were available.
Outlet: One 30″ circular concrete sewer discharges all wastes, except sanitary, to Perry Creek.
The water below the outlet had a dark gray color and some deposits were visible on the stream bank.
Sanitary Sewage: Discharged to city sewer; 200 persons tributary.


FLOW DIAGRAM
PULP MILL
Water Supply
Logs
Saws Bark Drums
Dust & Bark
Wash
Chipper
Furnace
Chemicals
Chip Screen
Dust
Recovery Process
Digester
Blow Pit
Weak Black Liquor Storage
By-Products
Screen
Mixing Box
Riffler Knotter
Refiner (Jordan)
Refining Screen
Thickener
Decker (Thickener)
Water Storage
Calcium Hypochlorite
Bleach
Drier
Storage
Thickener
Dry Pulp
Paper Mill
NOTE
Indicates steps which are generally optional with the plant
Indicates flow of water supply or wastes.
Sewer, Stream, or Recovery Devices
OHIO RIVER POLLUTION SURVEY
U S PUBLIC HEALTH SERVICE
1942


FLOW DIAGRAM
PULP MILL BLACK LIQUOR
RECOVERY PROCESSES
SODA & SULFATE (KRAFT) LIQUORS
Wash Liquors
Blow Pit
Evaporator
Salt Cake-Na_2SO_4 (Sulfate Proc.)
Digester
Smelter $NaOH \rightarrow Na_2CO_3$ ($Na_2SO_4 \rightarrow Na_2S$)
Water and Weak Alkali
Leaching Cells
Carbon Residue
New Lime
Slaking Tank
Lime Kiln
Soda Ash (Soda Proc.)
Causticizer
Filter
Filter
White Liq. NaOH (Soda Proc.)
Green Liquor NaOH & Na_2S (Sulfate Proc.)
Measuring Tank
SULFITE LIQUOR
(HOWARD PROCESS)
Digester
Blow Pit
Save-all
Mixing Basin
Sludge
Coag and Settling
Air
Sulfur
Sulfur Burner SO_2 Cooker Gas Coolers
Coag. and Settling
Sludge
Vacuum Filter
Lime stone Tower
Coag and Settling
Sludge
Fuel Cake
Reclaiming Tank
Heat Exchanger
Lime
Accumulator
Effluent
Slaker
Clarifier
Grit
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U. S. PUBLIC HEALTH SERVICE
1942

OHIO RIVER POLLUTION SURVEY - U.S.P.H.S. - CINCINNATI, OHIO

I-8
Rev. 8-39

PULP AND PAPER MILL WASTES (Not an Actual Plant)

Plant Burden Pulp Co. State Ohio Ref. No. CP-217

City Fair City County Weaver Main Watershed Chase River

Address 600 Main Street Sub-watershed Perry Creek

Informant A. B. Chester Title Gen. Super. Principal Product Pulp

Plant Operation:	Hours per Week	Days per year	Plant Employees
Average	144	300	200
Maximum			

Seasonal variation None

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial	City	3,500,000		None
Cooling	Creek	No est.		"

RAW MATERIALS:- Wood 140 cords spruce/day Soda pulp

Sulphite pulp Old paper

Groundwood pulp Straw

Paper shavings Rags

Chemicals:- ~~Clay~~ Sulfur 17,500 lbs./day ~~Talc~~ Limestone 21,000 lbs./day

Alum Size Soda ash

Caustic soda Bleaching Powd. 28,000 lbs./day Dyes

PRODUCTS:- Capacity in T/day 80 T./day Normal operation 70 T./day

Bleached sulfite pulp, air dried, 10% moisture

WASTES:- Quantity 3.5 M. G. D. How estimated Meter records

Character Washings - 2 m.g.d.; process - 1.5 m.g.d.

Disposal other than water carried Bark and sawdust burned

Dump of stock chest when change colors

Possible spills None reported

Segregation of Strong Wastes

Difficulties

Treatment Fine screen save-all Recovery practices

Analyses:- Number None Date By whom

Appearance Turbid

OUTLET:- Where to Perry Creek

Description:	Size and shape	Material	Location	Elevation
1.	30" circ.	Concrete		
2.				
3.				

Gaging possibilities Good. Manhole in sewer

Conditions below outlet: Color Dark gray

Turbidity Deposits Below Outlet

SANITARY SEWAGE: Disposal City sewer Persons tributary 200

REMARKS Ashes used for fill.

Survey by D. E. Fowler Date 5-17-39

TYPICAL INSPECTION REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I-8

INDUSTRIAL WASTES (*Not an actual plant*)

River Mileage Index No. *MR-21.7*

Type of Plant: *Paper Mill.* State: *Ohio.*
Name of Plant: *Ordon Paper Co.*
Municipality: *Jonesville.* Main Watershed: *Midway River.*
County: *Whipple.* Subwatershed: *Rangoon Creek.*
Address: *2300 Broadway.*
Source of Information: *A. B. Clarke, Plant Superintendent.*
Plant Operation:

144 hours/week—300 days/year.
Average 375 plant employees.

Seasonal Variation: *Very little.*

(Survey report continued on next page)

Survey by *D. E. Fellows.* Date: *7-14-40*

Sewered Population Equivalent Computation:

Factors used per *ton paper produced daily:*

B. O. D.: *40.* Suspended solids: *217.*

Sewered population equivalent* based on B. O. D.: *10,000.*
Sewered population equivalent* based on suspended solids: *54,000.*

Remarks: *P. E. based upon normal daily production.*
Computation by *G. H. Inman.* Date: *12/9/40.* Cincinnati Office

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
*Rounded to nearest two significant figures.

(*Typical inspection report continuation sheet*)

Ordon Paper Co., MR-21.7
Jonesville, Ohio.
Water Supply:

	Million gallons per day		Source	Treatment
	Average	Maximum		
Drinking and industrial	7	8	Wells	Boiler water softened.
Cooling	7	9	Creek	None.

Raw Materials Tons/day:

Soda Pulp	7.1
Sulfite Pulp	105
Groundwood Pulp	1.4
Sulfate Pulp	125
Paper Shavings	20.6
Rag Pulp	2.1
Clay	2.5

Raw Materials Tons/day—Con.

Talc	0.2
Alum	4.5
Rosin	1.7
Soda Ash	1.3
Caustic Soda	0.2
Bleach	1.1
Dyes	104

Products—Specialty paper products:

Production capacity ......275 Tons/day.
Normal production ....250 Tons/day.

Wastes: Average 14 M. G. D.—7 M. G. D. cooling water, 3.5 M. G. D. washings, 3.5 M. G. D. process wastes. Estimates based upon capacities and operating schedules of the pumps. No disposal other than water carried.

Spills occur occasionally from chests running over. There is no treatment except a save-all on the screen-felt shower and press wastes.

No analyses were available.

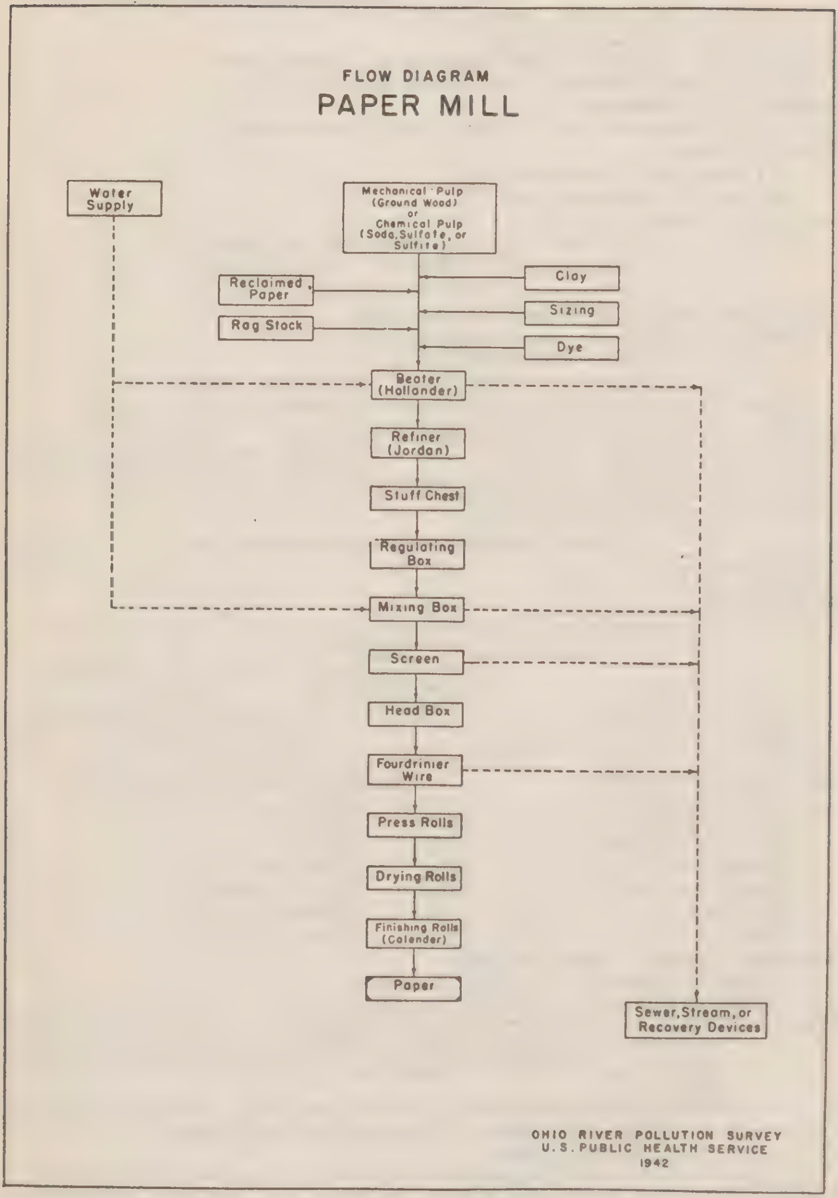
Wastes have a white appearance and contain some suspended matter.

Outlets: There are several separate outlets varying in size from 10″ to 30″ and all discharging to Rangoon Creek. Gaging would be difficult because of the large number of outlets.

An inspection of conditions below the outlet showed a white color, high turbidity, and some deposits.

Sanitary Sewage: Discharged to city sewers; 375 persons tributary.

Remarks: Very little recirculation is practiced because of the frequent color changes.


FLOW DIAGRAM
PAPER MILL
Water Supply
Mechanical Pulp (Ground Wood) or Chemical Pulp (Soda, Sulfate, or Sulfite)
Reclaimed Paper
Rag Stock
Clay
Sizing
Dye
Beater (Hollander)
Refiner (Jordan)
Stuff Chest
Regulating Box
Mixing Box
Screen
Head Box
Fourdrinier Wire
Press Rolls
Drying Rolls
Finishing Rolls (Calender)
Paper
Sewer, Stream, or Recovery Devices
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1942

PULP AND PAPER MILL WASTES (Not an Actual Plant)

Plant: Ordon Paper Co. State: Ohio Ref.No. MR-21.7

City: Jonesville County: Whipple Main Watershed: Midway River

Address: 2300 Broadway Sub-watershed: Rangoon Creek

Informant: A. B. Clark Title: Plant Super. Principal Product: Paper

Plant Operation:	Hours per Week	Days per year	Plant Employees
Average	144	300	375
Maximum			

Seasonal variation: Very Little

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking				
Industrial	Wells	7,000,000	8,000,000	Boiler water soft.
Cooling	Creek	7,000,000	9,000,000	None

RAW MATERIALS:- Wood: Soda pulp: 7.1 T./day

Sulfate ~~Sulphite~~ pulp: 125 T./day Sulfite Pulp ~~Old paper~~: 105 T./day

Groundwood pulp: 1.4 T./day. Straw:

Paper shavings: 20.6 T./day. Rags: (Pulp) 2.1 T./day

Chemicals:- Clay: 2.5 T./day Talc: 0.2 T./day

Alum: 4.5 T./day ~~Size~~ Rosin 1.7 T./day Soda ash: 1.3 T./day

Caustic soda: 0.2 T./day Bleach: 1.1 T./day Dyes: 104 T./day

PRODUCTS:- Capacity in T/day: 275 Normal operation: 250

Specialty paper products

WASTES:- Quantity: 14 M.G.D. How estimated: Pump capacities

Character: Cooling - 7 m.g.d.; washings - 3.5 m.g.d.; process - 3.5 m.g.d.

Disposal other than water carried: None

Dump of stock chest when change colors:

Possible spills: Occasional from chests running over

Segregation of Strong Wastes: Screen felt shower and press wastes to save-all

Difficulties: None reported

Treatment: Save-all Recovery practices:

Analyses:- Number: None Date: By whom:

Appearance: White

OUTLET:- Where to: Rangoon Creek

Description:	Size and shape	Material	Location	Elevation
1.	Several outlets ranging			
2.	from 10" to 30"			
3.				

Gaging possibilities: Poor - several outlets

Conditions below outlet: Color: White

Turbidity: High Deposits: Below outlets

SANITARY SEWAGE: Disposal: City Sewer Persons tributary: 375

REMARKS: Little recirculation - frequent color changes

Survey by: D. E. Fellows Date: 7-14-40

APPENDIX XI OF SUPPLEMENT D

TANNERY

An Industrial Waste Guide to the Tannery Industry

CONTENTS

Abstract

A vegetable tannery engaged in converting raw hides into leather produces waste principally from the processes of cleaning, unhairing, and fleshing the hides, from the tanning process, and from bleaching of the tanned leather. The wastes contain hide substance, hair, fats, and the various chemicals used in the process, principally lime, sulfides, tannins, soda ash, and sulfuric acid. The combined wastes are usually highly alkaline although the wastes from the tanyard and part of the bleach wastes are acid. The wastes are particularly high in suspended solids because of the presence of large amounts of undissolved lime. Spent tan liquor and the soda bleach wastes are strongly colored and this color is very difficult to remove.

One hundred pounds of green salted hide, as received at the tannery, will produce about 68 pounds of finished leather. Ohio Basin tanneries employ an average of about 7 men per 100 pounds of hide processed per day. The combined wastes from the tannery amount to about 800 gallons per 100 pounds of hide and contain about 2,400 parts per million of suspended solids and 1,200 parts per million of biochemical oxygen demand. The sewered population equivalents of vegetable tanning wastes are about 48 (biochemical oxygen demand) and 80 (suspended solids) per 100 pounds of hide per day. All of these figures are subject to wide variations.

The only treatment method in common use is mixing of acid and alkaline wastes followed by sedimentation. Various secondary treatment devices have proven successful in experimental plants but the high cost of such treatments has prevented their wide use. Chemical precipitation using various chemicals has been studied and found effective but expensive. The sludge disposal problem is difficult. From 7 to 10 percent of the waste volume is sludge. Drying beds or lagoons are the standard methods of dewatering the sludge. Vacuum filters and centrifuges have not yet proved satisfactory. The sludge has some value as a fertilizer.

Wastes from chrome tanneries are considerably weaker than those from vegetable tanneries. Limited data indicate sewered population equivalents to be about 24 (biochemical oxygen demand) and 40 (suspended solids).

Description of Process

Raw hides and skins are made into leather by tanning. The two principal processes in use are vegetable tanning and chrome tanning. In either case the raw or salted hides delivered to the tannery are cleaned and the hair and flesh removed prior to the actual tanning process. This is done in the beam house and, in general, the methods used are the same regardless of the method of tanning although they vary considerably in detail from plant to plant, depending largely on the type of

skin or hide being handled and the product desired. In the tanyard the prepared skins are immersed in the tanning agent, either an extract of the bark, wood, or nuts from various trees or a solution of chromium salts. After tanning, the leather is dried and finished in the finishing department.

Most of the tanneries operating in the Ohio Basin produce "heavy" leather; i. e., sole and belting leather, and use the vegetable tanning process. The processes described here are typical of a sole leather tannery.

BEAM HOUSE

(*a*) *Soaking.*–Salted cow and steer hides are soaked in vats of water for 1 or 2 days to clean and soften them.

(*b*) *Liming.*—The hides are placed in vats containing solutions of lime and sodium sulfide which loosen the hair by dissolving the outer hide layers. This requires from 3 to 7 days.

(*c*) *Warm pool* (*optional*).—The hide is soaked in warm water for about 1 hour.

(*d*) *Unhairing.*—White hair is removed by hand, because of its higher market value, and the remainder is removed by machine.

(*e*) *Fleshing.*—The flesh attached to the inner surface of the hide is removed roughly by hand and machine.

(*f*) *Wash wheel.*—The hides are placed in revolving drum where they are tumbled about while clean water carries away the lime.

(*g*) *Deliming.*—The lime remaining in the washed hide is removed by either water alone, or a bath containing a small amount of acid.

(*h*) *Bating.*—The hide is placed in a solution containing proteolytic enzymes buffered with ammonium salts.

TAN YARD

(*a*) *Rockers.*—The hides are suspended from rocker frames (dipping motion) in vats of vegetable tan liquor and are exposed to progressively stronger liquors.

(*b*) *Layers.*—From the head rocker the hides pass to the layer vats containing the heavy tanning liquor in which tanning is completed. The length of time required for tanning varies considerably but the average is about 70 days. There is a tendency toward shortening the time required.

FINISHING DEPARTMENT

(*a*) *Bleaching.*—The tanned hide is passed to the scrub house where it is bleached in a sodium carbonate solution followed by a bath in dilute sulfuric acid to neutralize the excess soda, and finally a dip in water.

(*b*) *Other finishing.*—Processes such as impregnation with oils, concentrated tanning liquors, sugar, salt, etc., are used, depending on the type of product desired.

In chrome tanning the hides from the beam house are pickled in a bath of salt and acid for about 1 hour, then tanned in a mixture made by reducing sodium bichromate and sulfuric acid with glucose. This may take from several hours to several days. Treatment with alkali, such as sodium bicarbonate, usually folllows to neutralize the excess acid. Chrome tanned leather is not bleached. Some tanneries use both processes.

Raw Materials and Products

Salted cow and steer hides are commonly used for heavy leather. These hides vary considerably in weight. At the tanneries surveyed in connection with the Ohio River pollution survey the reported average weight varied from 35 to 65 pounds and the over-all average was about 52 pounds. These same plants reported from 62 to 75 pounds of leather per 100 pounds of salted hide with an over-all average of 68 pounds.

Vegetable tan liquors are composed chiefly of infusions of chestnut wood, quebracho wood, and hemlock or oak bark. An increasing number of tanneries buy tanning extract although many still make their own extract from tan bark for at least a part of their needs.

The principal chemicals used are lime and sodium sulfide for hair loosening and soda ash and sulfuric acid for bleaching. The average amounts of these chemicals used at plants in the Ohio Basin where such data were available were:

	Pounds per 100 pounds of hide
Lime	10
Sodium sulfide	.25
Soda ash	.75
Sulfuric acid	2

These amounts of lime and sulfuric acid are said to be representative of general practice but the amounts of sodium sulfide and soda ash are said to be only about half of the amounts ordinarily used.

Lactic acid is used in some tanneries in deliming and, if the hides are bated, ammonium salts and proteolytic enzymes are used. Various dehairing agents are used with lime in different tanneries. The more important ones are sodium sulfhydrate, dimethylamine, and arsenic sulfide.

The number of employees per 100 pounds of hide processed per day varied from about 4 to 15 in 22 vegetable tanneries in the Ohio Basin. The average was about 7 employees per 100 pounds of hide per day. In general, the larger plants had fewer employees per unit of product than the smaller ones.

Sources of Wastes

Beam house:
- Soak water.
- Lime vat liquors.
- Warm water pool liquors.
- Unhairing machine water.
- Hair washing water.
- Fleshing machine water.
- Wash wheel water.
- Deliming process water.

Tan yard:
- Spent tan liquor.
- Vat rinses, leather rinses, leakage.

Finishing department: Bleach liquor.

Quantity and Character of Wastes

The amount of waste produced by tanneries has been found to vary from about 300 to 1,700 gallons per 100 pounds of hide processed. Howalt and Cavett reported that the waste flow of 617 gallons per 100 pounds of hide at the Instanter, Pa., tannery was about the average of 51 plants in 10 States. Data on 18 Pennsylvania vegetable tanneries show variations of from 300 to 1,300 gallons, with an average of 730 gallons per 100 pounds of hide. Twenty-one tanneries in the Ohio Basin have waste flows of from 400 to 1,700 gallons per 100 pounds of hide and an average of 800 gallons. From 700 to 800 gallons per 100 pounds of hide seems to be a fairly representative figure for the average vegetable tannery, but there is ample evidence that, if necessary, tanneries can reduce their waste flows considerably below these average amounts without interfering with the quality of the product.

Several hundred analyses of the combined wastes from various tanneries in Pennsylvania, West Virginia, Michigan, Tennessee, North Carolina, and Kentucky indicate that the following is fairly representative of the character of the combined wastes from a vegetable tannery.

Waste volume	gallons per 100 pounds of hide	800
Total solids	parts per million	7, 200
Volatile solids	do	3, 600
Suspended solids	do	2, 400
Biochemical oxygen demand (5-day 20° C.)	do	1, 200
Color (A. P. H. A.)	do	3, 500
pH		11

Anthrax spores may be present in the wastes and in the recovered products such as fertilizer.

The character of the wastes from individual steps in the process are as follows:

BEAM HOUSE WASTES

Soak waters, discharged intermittently, contain dirt, dung, blood, and other soluble proteins, salt, hair, and sometimes degradation products as major impurities. They have a dark, dirty, olive green color.

Lime-vat effluents, discharged intermittently, contain dirt, hair, dissolved putrescible organic materials, and lime. They have a bluish milky appearance.

Warm-pool wastes, discharged intermittently, are similar in character and appearance to the lime vat discharged but are much weaker.

Unhairing-machine wastes are discharged continuously, contain lime and fine hair, and are slightly turbid.

Hair washes are discharged continuously and are similar to unhairing-machine wastes but somewhat weaker.

Fleshing-machine wastes are continuous, contain small pieces of flesh and fat, and are highly putrescible.

Deliming wastes are discharged continuously, contain small amounts of lime and hide substance, are slightly turbid. If bating is done, the bate liquors are discharged intermittently.

TAN YARD WASTES

Spent tan liquor from the tail rockers, discharged intermittently, is the worst single waste as regards color, solids, and biochemical oxygen demand. It is reddish brown in color and is acid.

Rinse liquors sometimes used to wash hides at this point in the process are similar in character to spent tan liquor. These wastes are often returned to the process and are not discharged.

FINISHING-DEPARTMENT WASTES

Bleach wastes, discharged intermittently, contain spent soda and acid solutions, and rinse water which is also acid. It is usually colored.

Other finishing processes ordinarily do not produce wastes.

The wastes from the beam house are alkaline while the tanyard and bleach wastes are acid.

Table T–1 shows the approximate amounts and representative analyses of the individual effluents. Both the amount and character of the wastes vary widely from plant to plant.

TABLE T–1.—*Approximate quantity and character of wastes from various steps in vegetable tanning process (heavy leather)*

Waste	Volume, gallons per 100 pounds of hide per day	Total solids, parts per million	Suspended solids, parts per million	Biochemical oxygen demand, 5-day, parts per million	Percent of total solids	Percent of biochemical oxygen demand
Soaks [1]	80	12,000	1,200	600	17	5
Limes [1]	40	27,000	10,000	2,400	19	10
Warm water [1]	50	10,500	3,500	1,000	9	5
Unhair	25	2,500	1,500	400	1	1
Hair wash	40	2,000	1,200	200	1	1
Fleshing	35	3,500	2,600	800	2	3
Wash wheel	200	1,600	450	700	6	15
Float box	30	300	150	25	0	0
Green stock	210	400	100	3	1	0
Spent tan [1]	50	27,000	1,500	10,000	23	52
Bleaches [1]	40	30,000	1,200	2,000	21	8

[1] Intermittent discharges.

This table shows that the intermittent discharges which represent about one-third of the total waste volume contain almost 90 percent of the total solids and 80 percent of the biochemical oxygen demand of the combined wastes. The figures shown in table T–1 for suspended solids cannot be used to determine the suspended solids content of the combined wastes since, upon mixing, some of the dissolved or colloidal solids in the individual wastes are precipitated. Many plants use a slush wheel as the first beam house process to clean the hides of gross filth before soaking. Bating is the last beam house process. Insufficient data prevent including representative quantities and analyses of the wastes.

Available data indicate the sewered population equivalent of combined vegetable tannery wastes to be about 48 per 100 pounds of hide processed on a basis of biochemical oxygen demand and about 80 per 100 pounds of hide on a basis of suspended solids. The beam house contributes about 89 percent of the waste volume and 40 percent of the boichemical oxygen demand. The spent tan liquor constitutes about 6 percent of the volume and 52 percent of the biochemical oxygen demand and the bleaches about 5 percent of the volume and 8 percent of the biochemical oxygen demand.

Data on chrome tanneries are somewhat less complete. Studies at the tannery testing station of the Sanitary District of Chicago in 1920–22 showed a population

equivalent of about 22 per 100 pounds of hide based on biochemical oxygen demand and 34 based on suspended solids. The waste flow was about 845 gallons per 100 pounds of hide. More recent studies at a Waukegan, Ill., chrome tannery indicated population equivalents of about 36 and 57 based on biochemical oxygen demand and suspended solids respectively. The average waste flow was 1,410 gallons per 100 pounds of hide and included an appreciable amount of infiltration. These studies showed that about 95 percent of the biochemical oxygen demand, 91 percent of the total solids and 85 percent of the suspended solids came from the beam house wastes. At 18 Chicago chrome tanneries sampled during 1936 biochemical oxygen demands varied from 300 to 3,000 parts per million with a weighted average of 930 parts per million and suspended solids varied from 500 to 3,300 parts per million with a weighted average of 1,310 parts per million. No production figures are available with which these analyses can be correlated.

Assuming the beam house wastes from a chrome tannery to be the same as those from vegetable tanneries, the population equivalent based on biochemical oxygen demand should be about one-half as great for the chrome tannery as for the vegetable tannery. Actually, the beam house wastes may differ appreciably since the chrome process is used largely in making the lighter types of leather. No data are available to indicate the effect of these variations on the strength and amount of wastes. Suspended solids seem to be higher than the biochemical oxygen demand in most instances although at seven of the Chicago tanneries the situation was reversed. Sewered population equivalents of 24 (biochemical oxygen demand) and 40 (suspended solids) seem reasonable.

Pollution Effects

Tannery wastes exert a deoxygenating effect on the receiving stream. In addition, the large amounts of suspended solids often cause sludge banks in the stream which continuously deplete the dissolved oxygen in the stream and cause obnoxious odors. The color of vegetable tanning liquors is very strong and persistent. The liquor reacts with iron to form an inklike substance which may be noticeable for many miles downstream. The intermittent discharge of the stronger wastes accentuates the pollution problem.

Untreated tannery wastes have caused considerable difficulty in municipal sewers by the deposition of suspended solids and the formation of calcium carbonate scale on the sewers. The caustic alkalinity in the wastes may also damage biological processes of sewage treatment if the tannery wastes constitute an excessively large part of the waste flow. Chrome salts from chrome tanneries may be toxic to the organisms necessary for sludge digestion.

There is relatively little danger of anthrax being present in native hides and skins since the disease is fairly well under control in this country. It is standard practice to disinfect all suspected hides at the tannery before processing.

Remedial Measures

Hair, fleshings, and hide trimmings are commonly collected and sold. The hair is washed, dried, and sold for use in the manufacture of rug pads, plaster binders, etc. The fleshings and trimmings are used in making glue. The fleshings may also be processed to obtain oil and grease. Leather trimmings are used in making artificial leather.

Lime sludge which settles to the bottom of the liming vats contains dirt, hair, and organic matter. When discharging the wastes from the lime vats, this sludge may be allowed to remain in the vats or the entire contents may be mixed well and discharged. The sludge can be shoveled out after the tank has been drained and used as fertilizer or for liming fleshings. If discharged with the rest of the lime liquor, it adds greatly to the suspended solid load of the wastes and to their causticity.

Spent tan liquors may be condensed for reuse as a tanning agent or evaporated and the residue sold as boiler compound. Its use as a road material or a foundry core binder has been suggested. Spent tanbark is commonly burned. Where freight rates permit, it is used in the manufacture of white lead. It may also be used in making paperboard. Constant improvements in the tanning process promise to reduce to an important degree the amount of spent tan liquors discharged. Considerable progress has been made in this direction in recent years.

The use of dimethylamine or similar products in place of sodium sulfide as an aid in unhairing helps to reduce the biochemical oxygen demand of the wastes and eliminates a considerable part of the sulfides. Although the cost of dimethylamine is now greater than that of other depilatories, it has certain desirable qualities

which may lead to its wider use with a consequent reduction in the strength of the wastes.

Sedimentation of either the combined wastes or of the stronger wastes is the only method of tannery waste treatment in common use today. Numerous studies of tannery waste treatment have been made in this country, particularly by the pollution abatement authorities of Pennsylvania, Massachusetts, and Michigan, in cooperation with industrial groups and by the Sanitary District of Chicago in connection with the design of its treatment plants. The problem has also been widely studied abroad with results similar to those obtained in this country.

PRIMARY TREATMENT

Mixing of the wastes and sedimentation has been found, in experimental plants, to remove about 70 to 80 percent of the suspended solids and about 40–50 percent of the biochemical oxygen demand. Approximately the same percentage removals of suspended solids are obtained when tan liquors are excluded as when they are treated with the rest of the wastes. Exclusion of tan liquors increases the percentage removal of biochemical oxygen demand. Limited data on full-scale plants in actual operation indicate that the suspended solids removals are about as high as in the experimental plants but biochemical oxygen demand results are less satisfactory in many cases.

A survey by the Massachusetts State Board of Health in 1934 of the pretreatment works at 47 tanneries in Peabody and 25 in Salem, Mass., showed the weighted average removal of suspended solids to be about 41 percent in Peabody and 36 percent in Salem. The average detention period of the sedimentation tanks in Peabody was found to be 3.0 hours and in Salem 1.1 hours. Many of the tanks were not being operated properly.

Most of the tannery waste treatment plants in the Ohio Basin provide detention periods of 24 hours or more. In Pennsylvania secondary sedimentation is usually provided in basins from which a uniform outflow rate throughout the day is maintained by means of perforated, horizontal, float-supported pipes acting as outfall weirs, discharging through swinging drawdown pipes and float-controlled orifice boxes. Both continuous flow and fill and draw tanks are in common use for primary sedimentation. In the former, continuous sludge collecting mechanisms are used. In the fill and draw plants sludge collecting equipment is not provided These plants usually include three primary tanks, one of which is always out of service for cleaning.

Where primary treatment is sufficient, it is often feasible to segregate the stronger wastes and treat them, discharging the wastes containing only small amounts of suspended solids without treatment. Segregation of the spent tan liquors and soda bleaches is common practice where color reduction is desired. The remaining wastes are usually settled. The tan liquors and soda bleaches are lagooned and discharged to the stream during periods of high flow.

Because of the great differences in the individual components of tannery wastes, it is usually desirable, though not always practicable, to mix the wastes in a definite order rather than allowing them to mix in a haphazard manner as discharged. Considerable study was given this matter by Howalt and Cavett in treating the combined wastes from the Instanter tannery and by Maskey in treating only beam house wastes. It is difficult to generalize on the results of these studies because of differences in processes at various tanneries but in the design of treatment works it is desirable to consider the possibilities of controlled mixing of the wastes. Such treatment may require considerable changing of plant sewers, the construction of sumps or holding tanks, multiple pumping, and may complicate operation.

CHEMICAL PRECIPITATION

Coagulation takes place to a considerable degree upon mixing of the plant wastes. A number of experiments have been made to determine a method of increasing the efficiency of treatment by the addition of chemicals. In many of these experiments the use of an acid (CO_2, H_2SO_4, SO_2) has been used to reduce the pH of the wastes to below 7.0 (usually 5.5–6.5) followed by the use of one of the common coagulants. Flue gas and lime were used by Riffenburg and Allison. Sulfuric acid or sulfur dioxide and either aluminum sulfate or lime or both were used by Howalt and Cavett. Flue gas and ferric chloride were used by Maskey. Sarber found that sulfuric acid gave approximately the same results as flue gas when used with ferric chloride. The use of various coagulants without acidification has also been studied

In most instances the added efficiency due to chemical treatment has been found to be too small to justify the use of chemicals as a general practice. The

principal use that has been made of chemical treatment is to reduce the caustic alkalinity of the wastes in order to prevent the deposition of calcium carbonate in sewers. Clark's experiments led to the adoption of the flue gas for reducing the caustic alkalinity of tannery wastes which were causing trouble by clogging the sewers at Peabody, Mass.

SECONDARY TREATMENT

Further treatment by the various biological treatment devices in common use has been successful in experimental plants but relatively little has been done in actual practice. Fales states that intermittent sand filters have been successfully operated at several Massachusetts tanneries. At Gloversville, N. Y., where wastes from about 25 tanneries are treated with the municipal sewage from a town of 23,000 people, a plant with trickling filters followed by intermittent sand filters has been in successful operation for more than 30 years. At Elmshorn in northern Germany an activated sludge plant treats a mixture of about one-half tannery waste and one-half domestic sewage, removing about 80 percent of the biochemical oxygen demand of the combined wastes.

In general, experimental work has shown that intermittent filters with either sand or cinder filter media are the most efficient devices for color removal as well as for reduction in biochemical oxygen demand. Trickling filters are somewhat less efficient for removal of biochemical oxygen demand and much less efficient in removing color. Activated sludge is more easily upset by occasional overloads or by causticity of the applied waste than either trickling filters or intermittent filters. No data are available on the suitability of recirculating filters for treating tannery wastes.

Extensive experiments in Pennsylvania and Michigan indicated that mixture of the wastes, sedimentation and filtration, using trickling filters would reduce the suspended solids content by about 85 to 95 percent, the biochemical oxygen demand by 65 to 75 percent and the color by 15 to 70 percent. Although comparable data on the efficiency of intermittent filters are not available, the results of the Chicago tannery testing station indicated that intermittent filters were more efficient than trickling filters or activated sludge in removing both biochemical oxygen demand and color.

It is important that the wastes as applied to the filter not contain caustic alkalinity. Seeding of the filter with the proper organisms is necessary. At the Chicago tannery testing station it was found that the filter could be started by treating only the soak liquors from the tannery. Sarber developed an efficient growth on a trickling filter treating beam house wastes by seeding it with pure cultures of proteolytic organisms isolated from soak liquors, sewage, manure, etc.

SLUDGE DISPOSAL

One of the major problems in tannery waste treatment is sludge disposal. Approximately 7 to 10 percent of the total waste volume must be disposed of as sludge. Underdrained sludge drying beds do not appear to be appreciably more efficient than those not underdrained. Pennsylvania recommends equipping the beds with skimming pipes to remove the clean supernatant liquor and rain water. Lagoons are used extensively where land is available. The sludge has some value as fertilizer and is valuable on acid soils because of its high lime content. Vacuum filters and centrifuges have been used to some extent but are not wholly satisfactory.

SIZE OF UNITS

Primary and secondary sedimentation tanks are usually designed to provide 24 to 36 hours detention. They should be equipped with paddles for mixing during the period when wastes are entering the tank. Pennsylvania and Michigan recommend operating rates of from 1.25 to 1.50 million gallons per day per acre for trickling filters. Lagoons for storage of spent tan liquors and soda bleaches should provide about 325 gallons capacity per pound of hide per day. Sludge beds should provide about 1 square foot of area per pound of hide per day.

Suggested designs of waste treatment works are included in the Pennsylvania Department of Health bulletin Treatment of Tannery Wastes and in Michigan Engineering Experiment Section Bulletin No. 82.

COSTS

The most complete data on the cost of tannery waste treatment are contained in the above-mentioned Pennsylvania bulletin. They are based on the experience obtained in designing, building, and operating the full-scale experimental

plant at Emporium. The tannery handles 13,500 pounds of hide per day.

Estimated capital costs were:	
Mixing and sedimentation, 24-hour discharge	$22, 500
For filtration and resetting add	7, 000
Annual operating costs (307 operating days):	
Mixing and sedimentation, 24-hour discharge	2, 300
With chemical precipitation	6, 700
For primary filtration add	1, 500
For secondary filtration add	1, 000

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TYPICAL INSPECTION REPORT

(*First sheet on form. Entered information in italics*)

OHIO RIVER POLLUTION SURVEY—U. S. P. H. S.—CINCINNATI, OHIO I–10

INDUSTRIAL WASTES (*Not an actual tannery.*)

River Mileage Index No. *RH–165*

Type of Plant: *Vegetable Tannery.* State: *Kentucky.*
Name of Plant: *Hyde Tanning Company.*
Municipality: *Black Springs.* Main Watershed: *Roaring River.*
County: *Yancey.* Subwatershed: *Hemlock Creek.*
Address: *418 Limestone St.*
Source of Information: *C. G. Hyde, company president.*
Plant Operation:
48 hours per week, 300 days per year.
100 employees ave.
Seasonal Variation: *Slight variation.*
(Survey report continued on next page)
Survey by *W. Wimple.* Date: *8–24–39*

Sewered Population Equipment Computation:
Factors used per *100 pounds of hide per day:*
B. O. D.: *14.* Suspended solids: *16.*
Sewered population equivalent* based on B. O. D.: *2,100.*
Sewered population equivalent* based on suspended solids: *2,400.*
Remarks: *Allow 70% reduction in B.O.D. for evaporation of spent tan liquors and sedimentation. Allow 80% reduction in suspended solids for treatment.*
Computation by *C. W. Holmes.* Date: *9–12–39.* Cincinnati office.

NOTE.—This computation is of a preliminary nature and may be subject to revision as more information on this plant or the factors used becomes available.
* Rounded to nearest 100.

(*Typical inspection report continuation sheet*)

Hyde Tanning Co. RH 165
Water Supply: All water from municipal supply. Average 140,000 g. p. d. Boiler water zeolite softened. Other water untreated.
Raw Materials—Average quantities per day:

Salted cow and steer hides (ave. 52#)	15, 000 lb.
Lime	1, 500 lb.
Sodium sulfide	40 lb.
Soda Ash	120 lb.
Sulfuric Acid	300 lb.

Products: Sole Leather 10,500 lb. per day.
Wastes—115,000 g. p. d. (estimated by treatment plant operator from measurements at outfall and by plant engineer from plant operations):

Soaks	12, 000 g. p. d.
Hot water	7, 500 g. p. d.
Limes	6, 000 g. p. d.
Acid Bleach	2, 000 g. p. d.
Soda Bleach	2, 000 g. p. d.
Acid Water	2, 000 d. p. d.
Other wastes (by difference)	83, 500 g. p. d.

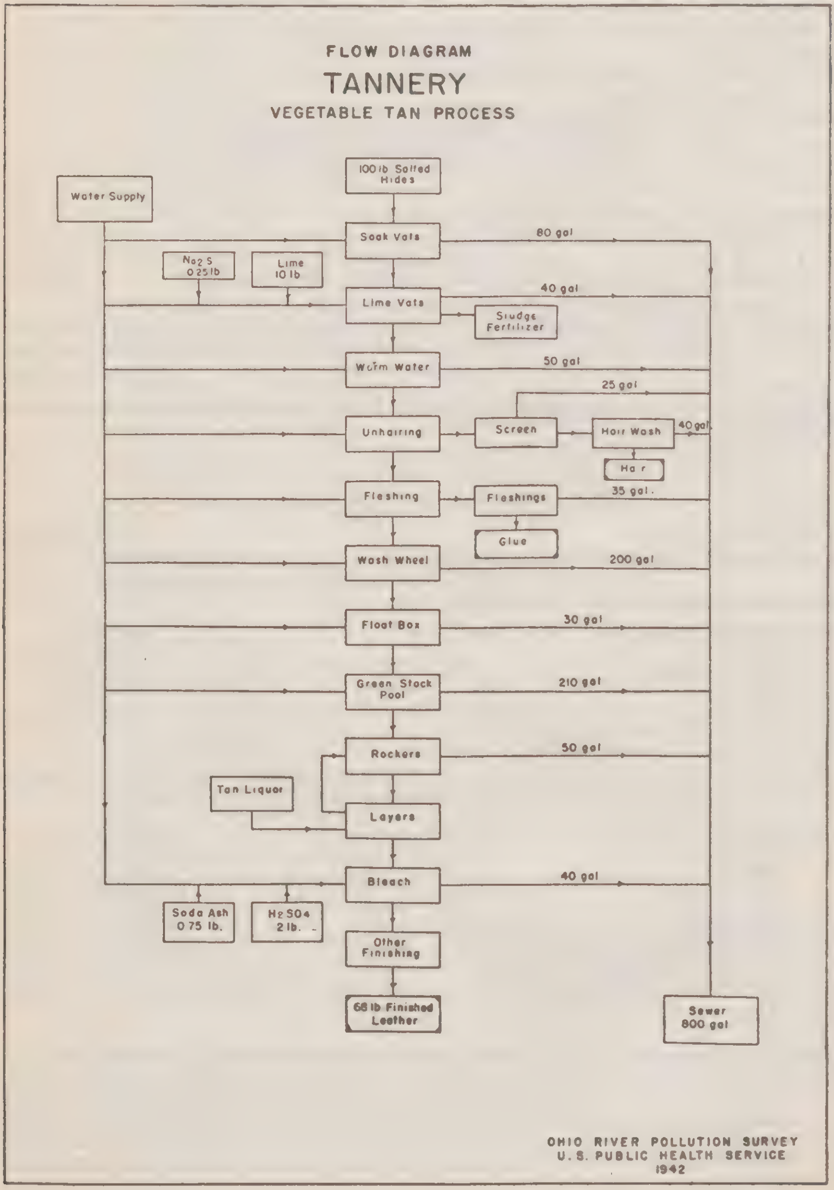
7,500 g. p. d. spent tan liquor evaporated. Residue sold for boiler compound.
Analyses: None.
Outlet: To treatment plant, outfall direct to Hemlock Creek through ditch.
Plant units include: (*a*) sump for raw wastes with automatic float controlled pump; (*b*) 45′ diameter Dorr clarifier, 120,000 gal. capacity; (*c*) earth equalizing basin, 120,000 gallons capacity, equipped with horizontal, perforated, float supported swinging collector pipe discharging to (*d*) float controlled orifice box which maintains a uniform outflow rate to Hemlock Creek.

Sludge from Dorr clarifier pumped to lagoon in low area adjacent to plant. Supernatent collected by ditches and returned to clarifier. Equalizing basin drained and cleaned on alternate Sundays. Sludge to lagoon. Farmers haul away part of sludge.

Gaging Possibilities: Good at either sump or orifice box.

Conditions below Outlet: Stream low at time of visit. Color, black. No sludge deposits apparent.

Remarks: Numerous complaints have been made about color of stream in the past. Color was apparent as far downstream as mouth of Hemlock Creek 25 miles away. Since installation of evaporators for spent tan liquor color is apparent for only about three miles downstream. No complaints recently.



TANNERY WASTES

Plant: Hyde Tanning Co   State: Ky.   Ref.No.: RH - 165

City: Black Springs   County: Yancey   Main Watershed: Roaring River

Address: 418 Limestone St.   Sub-watershed: Hemlock Cr.

Informant: C.G. Hyde   Title: President   Principal Product: Sole Leather

Plant Operation:	Hours per Week	Days per Year	Plant Employees
Average	48	300	100
Maximum			

Seasonal variation: Slight variation

WATER SUPPLY:-	Source	Av. g. p. d.	Max. g. p. d.	Treatment
Drinking / Industrial / Cooling	Municipal Supply	140,000		Boiler only
				Zeolite Softened

RAW MATERIALS:- Raw hides: 15,000 lb. salted Cow and Steer hides (average 52 lb. per hide)

Chemicals:- Lime: 1,500 lb. per day   Sulphuric Acid: 300 lb. per day

~~Chrome~~ Sodium Sulfide 40 lb. per day   Dye:

Other: Soda ash 120 lb. per day

PRODUCTS:- Sole Leather 10,500 lb. per day

WASTES:- Quantity: 115,000 g.p.d.   How estimated: Measurements at outfall, Vat capacities

~~Washings~~ Soaks 12,000 g.p.d.   Lime: 6,000 g.p.d.

Acid: bleach 2,000 g.p.d. acid water 2,000 g.p.d.   ~~Chrome~~ Soda bleach 2,000 g.p.d.

Dye: Other: Hot water 7,500 g.p.d.

Possible spills:

~~Grease trap~~ Other wastes 131,500 by difference

Analyses:- Number: None   Date: By whom:

Appearance: Black

OUTLET:- Where to: Treatment plant, private outfall through ditch to Hemlock Cr.

Description:	Size and shape	Material	Location	Elevation
1.				
2.				
3.				

Gaging possibilities: Good at raw waste sump or at outlet

Conditions below outlet: Color: Black

Turbidity: slight   Deposits: None visible

SANITARY SEWAGE: Disposal: Municipal Sewer   Persons tributary: 110

REMARKS: Spent tan liquors evaporated (7,500 g.p.d.) Residue sold as boiler compound. See attached sheet for data on treatment plant for other wastes.

Survey by: W Wimple   Date: 8-24-1939

SUPPLEMENT E

EPIDEMIOLOGICAL STUDIES

CONTENTS

EPIDEMIOLOGICAL STUDIES

Summary

Field studies of water-borne disease on the Ohio River watershed were made during the Ohio River Pollution Survey, 1939–40. These studies covered field epidemiological investigation of outbreaks of apparently water-borne disease; field bacteriological studies of these outbreaks; laboratory experimental studies, not definitely connected with outbreaks of disease, and statistical study of mortality from diarrheal and enteric diseases throughout the watershed.

Two outbreaks of gastroenteritis, a mild affliction characterized by nausea, vomiting, cramps, and diarrhea, lasting but a few days, and practically with no mortality, were studied in detail.

One outbreak of bacillary dysentery (Shiga), an acute illness, extending over several weeks with considerable mortality, was studied during the closing days of the survey. This outbreak of dysentery contrasts sharply with those of the mild, transitory gastroenteritis.

Evidence was obtained that this type of gastroenteritis is of infectious nature and water-borne. Experimental studies on human volunteers suggested the possibility that this form of gastroenteritis may be due to some hitherto unrecognized causal organism which may not be detected by the usual bacteriological tests applied to determine the potability of water.

Statistical evidence obtained in 43 cities of the Ohio River watershed indicate that filtration and chlorination of water supplies did not reduce the diarrhea and enteritis death rate to the same extent that these measures reduced the typhoid-fever death rate, basing this finding on a comparison of death rates for the 5-year period preceding the establishment of filtration and/or chlorination with the 5-year period immediately following installation of these water-purification procedures.

Water-Borne Disease Study

I. AIMS

The virtual conquest of water-borne typhoid fever along the Ohio River has been effected by the installation of adequate water treatment facilities in the great majority of the cities and towns using surface water supplies. There remains, however, an epidemic disease (by no means limited to the Ohio River Valley) generally considered to be carried by water and usually referred to as "gastro-enteritis, presumably water-borne." Individual cases of this ailment show symptoms of nausea, vomiting, cramps, and diarrhea lasting usually 1 to 3 days. So similar are the symptoms to the common food intoxications that patients are quite likely to attribute their trouble to something eaten at a recent meal, until they learn of numerous cases occurring simultaneously among friends and neighbors. Because

food poisoning is a relatively common occurrence and the symptoms, though often severe, have been experienced before, a physician is not likely to be called and extensive epidemics with cases occurring actually in the families of physicians have escaped medical attention entirely or have been dismissed as unimportant. Individual cases are not always easily distinguished from summer diarrhea or mild dysentery. The vomiting, the lack of fever, the short course, the watery, often fetid, stool, and the aversion to fluids despite often severe dehydration, are more typical of gastro-enteritis than of the above mentioned more ominous conditions.

Although individual cases are not always easily differentiated from the more common ailments noted above, the disease is easily identified by its behavior in groups of people—in other words, by its epidemiology. When the specific cause of a malady is unknown, it not infrequently happens that it can be more readily identified by its mass behavior than by the symptoms produced in individual cases. Thus influenza was formerly differentiated from grippe and other seasonal disturbances by its high attack rate and rapid spread from person to person. Water-borne gastro-enteritis—often erroneously diagnosed intestinal influenza—shows these same attributes in even more striking degree. As much as 80 percent of the population of a town has been known to be attacked within a period of 2 or 3 days to a week—a far more explosive condition even than influenza, which usually requires a full week, even in a small community, to reach its maximum prevalence and is not wholly over in 2 or 3 weeks. Like influenza, this form of gastro-enteritis is frequently a cold weather disorder and all ages are indiscriminately attacked. These characteristics assist in differentiating the condition from the food poisonings and summer complaints which tend to prevail in summer and early fall and attack the younger age groups more than the older. Quite striking, also, is the low mortality from water-borne gastro-enteritis when this is not accompanied by another more lethal water-borne condition, such as typhoid fever. Less than one person dies per thousand persons attacked and the occasional death usually occurs in individuals stricken with some coexisting acute or chronic disease—almost never in a previously healthy person.

As was noted above, the cause of true water-borne gastro-enteritis is obscure. Occasionally outbreaks have been explained on a chemical or specific bacteriological basis. Because the human gastro-intestinal tract has only a limited number of responses to a wide variety of harmful materials, it is not impossible that each outbreak may have a separate cause. It is known that the drinking of water contaminated with relatively small amounts of sewage can result in acute gastro-enteritis. Outbreaks of gastro-enteritis from this cause occurred more frequently two or three decades ago than they do at present, and were often followed by infections with the typhoid organism, then fairly common in sewage.

Sewage regularly contains great numbers of coliform bacteria, in and of themselves harmless, but valuable as indices of sewage contamination in drinking water. Tests for the detection of coliform bacteria are therefore made as a routine procedure in most water-treatment plants.

Occasional outbreaks of gastro-enteritis have been traced, however, to water in which sewage pollution was not found by the coliform

tests applied. The impression has crystallized among leaders in the water treatment field that causes other than sewage pollution may occasionally produce gastro-enteritis, and it was thought advisable to make a determined effort to learn the cause or causes of these outbreaks, so that, if really needed, further tests could be devised to insure the safety of drinking water.

Moreover, there was another cause for official concern. Physicians in attendance upon cases of summer complaint and the various diarrheal diseases of the warm months, puzzled by the almost epidemic prevalence of these conditions at times, not infrequently blamed the water supply either for inadequate treatment or for excess of chemicals.

The problem appeared therefore to be a twofold one—first, to determine the causes and prophylaxis of water-borne gastro-enteritis of hitherto undetermined etiology, and second, to learn enough, if possible, of the causes and mode of infection of summer complaints to determine their relationship to water as a possible vehicle of the ailment.

II. PERSONNEL AND EQUIPMENT

To fulfill this dual purpose the epidemiological unit was organized and equipped for a somewhat diversified attack on the problem by the late Surgeon Filip C. Forsbeck. His untimely death in July 1940 was a serious set-back for the study; arrangements were, however, made to complete the study very nearly in accordance with his original plans. The personnel consisted of Surgeon (R) Ralph E. Wheeler, epidemiologist in charge of the unit, who carried out field studies on outbreaks and supervised the work of other members of the unit, and Assistant Bacteriologist Wm. E. Burns, who examined water, stool, and other specimens secured in the course of the field work. For the preparation of media and glassware a laboratory assistant was assigned to the bacteriologist. Finally Assistant Statistical Clerk Frank P. McEnteer [1], was assigned to assist in the analysis of epidemic data and to help in epidemiological studies in the field during the course of outbreaks. The unit functioned under the administrative direction of Sanitary Engineer Director J. K. Hoskins, in charge of the Stream Pollution Investigations Station at Cincinnati, Ohio, who was succeeded in July 1940 by Medical Director H. E. Hasseltine.

The headquarters of the unit, which was a subdivision of the Ohio River Pollution Survey, were at the United States Public Health Service's Stream Pollution Investigations Station in Cincinnati, where extensive laboratory facilities and able advisory assistance were made available. The services of Sanitary Engineer Director H. W. Streeter and Principal Bacteriologist C. T. Butterfield were especially noteworthy.

Because it was recognized that water and stool specimens were best examined immediately, a trailer laboratory completely equipped for bacteriological study of pertinent specimens and samples was developed for work at the site of an outbreak.

Good relations with the health departments of the several States forming the Ohio River watershed were established early in the study and renewed by periodic collaboration on various projects. Outbreaks

[1] Deceased.

of water-borne gastroenteritis are not common and, because of their ephemeral character, it was necessary to keep in close touch with State health workers—particularly with the sanitary engineering groups, in order to learn of outbreaks during their early phases.

III. METHODS OF FIELD STUDY

When notification of a city or town outbreak was received from a State health department, the local health department having jurisdiction was contacted and permission obtained for participating in the The epidemiologist and statistical assistant usually preceded the laboratory, selected a central location for the trailer and arranged for the electric and other connections which it required.

Definite establishment of the fact that an epidemic was occurring was an early and vital feature of their work. This entailed (1) a study of school absences—which invariably show a sharp increase when an outbreak of any magnitude has begun—and (2) visits to local druggists to inquire whether sales of castor oil, bismuth preparations, and paregoric had shown a sudden sharp increase. When these inquiries to druggists are properly addressed, surprisingly uniform and frank responses are nearly always obtained. Druggists know the volume of their usual seasonal sales of these preparations and can give surprisingly good statements of the comparative sales during any period of inquiry. The files of recent local newspapers also give good data on the time at which the outbreak, if any, first came to public notice and on the antecedent local weather conditions. If, from these various preliminary inquiries, there was good basis for believing that an outbreak was in progress, a map of the local water distribution system was secured and a number of water samples was obtained from selected sampling points on the main grid of pipes, on all dead ends, and from the source of supply both before and after treatment, if any treatment was used. Besides subjecting these samples to bacteriological study, an important test made on these early samples (where chlorine was routinely used) was a test for residual chlorine.

Next, a house-to-house canvass was conducted of a random sample of the population. using the form shown in appendix I. This form was developed with a view to obtaining the most important information within a minimum of time. It can be filled in completely in less than 10 minutes in the average household, and two canvassers working for half a day can secure a very respectable population sample. Preliminary studies of this half-day's work usually give a fairly definite idea of whether water is the vehicle of the infection. In canvassing, an attempt was made first to secure a random sample of households straight across the town or city in one direction and then in another direction perpendicular to it. In this way geographic distribution of cases can be added to the information obtained from the age, sex, and other data of importance. In most localities a certain number of persons can be found who do not habitually use the city, or town, water supply for drinking purposes but resort, instead, to well, cistern, or bottled spring water. As large a sample of these individuals as possible was obtained early in order to determine the extent to which they were attacked. It is also important, where infants are living in a household, to determine whether their water and milk were boiled or given raw.

An intensive bacteriological study of the water supply was carried on coincidently with the epidemiological survey. In selecting sampling points, a careful inspection was made of the pumping station, treatment plant, and distribution system. On the distribution system points for sampling were selected so that freshly treated water would be tested as well as water from dead ends. To obtain more complete information concerning the bacterial content of the samples, two procedures were followed, (1) the sample was examined for coliform bacteria in accordance with standard methods to determine whether the water met the requirements of the Treasury Department standard, and (2) lactose broth tubes showing growth, but no gas, were examined to determine the type of bacteria present. In making determinations on portions of water much larger in volume than prescribed by standard methods, a concentration procedure was developed.

The samples were examined as soon as received. Portions of 10 milliliters each were measured into 10 tubes of lactose broth, incubated at 37° C. for 24 hours and examined. A second reading was also made after 48 hours. Those tubes which showed gas were transferred to brilliant green bile broth and streaked to MacConkey's agar plates at each examination period. A positive result in either medium was considered sufficient confirmation for the presence of members of the coliform group.

The tubes which showed no gas but did show the presence of growth were streaked on MacConkey's or other selective media plates, as the nature of the work might indicate, and the plates incubated 18 to 24 hours at 37° C. To obtain information regarding the flora, other than coliforms, present in the water, at least two representative non-lactose fermenting type colonies would be fished from each MacConkey plate to Russell slants. Russell's medium was used because it was considered worthwhile to learn something about the presence of proteus and the atypical slow lactose fermenting types which might be present. If the Russell tubes gave evidence of a consistent flora for the sample, one of the duplicate cultures was discarded at this point and the remaining cultures purified by streaking on MacConkey's agar, after short-time incubation in broth. Two well-isolated colonies were picked from the plate and again inoculated in Russell tubes. Where more than one type of colony appeared, two of each were fished. If these Russell tubes gave similar reactions, one culture only was retained for further study.

For the study of unfinished or raw waters the above procedure was modified as follows: If not highly polluted, five 10-milliliter portions were planted into lactose broth directly and three portions in each of several serial dilutions added as indicated. It was always considered essential to have at least one tube in the highest dilution which showed no growth. In all cases primary consideration was given to flora found in tubes with no gas formation or in the dilutions higher than that required to give the coliform index.

Because of the small number of bacteria to be found in treated water, a method of concentration was worked out and given practical test on water samples collected from Cincinnati and the surrounding communities within a radius of 75 miles. By this technique any desired portion of the water sample is filtered, with the use of suction, through an apparatus sold commercially under the name of Jenkins filter. By experimenting it was found that if the original filter blocks

supplied with the apparatus were cut to a thickness of approximately 3 to 5 millimeters, the filtration time for a 100-milliliter portion would be about 30 minutes.

Control tests were run on water samples known to be contaminated and on known suspensions of coliforms in distilled water. If the filter disk did not retain greater than 95 percent of the organisms it was discarded. With but few exceptions the filtrates were sterile. If there were many bacteria or an increased amount of inorganic material in the sample, difficulties were met in filtering. In the experimental work two portions of 100 milliliters each were filtered. The rubber sleeve holding the filter disk containing the bacteria was removed from the apparatus and with sterile rod the disk was pushed into a tube of enriched medium. Lactose broth and selenite F were used for enrichment. Incubation was at 37° C. and after growth appeared, the material was streaked on MacConkey or other selective media plates, the colonies fished and purified, with the technique outlined above. A comparison of the results of the concentration technique against the results from the ten 10-milliliter portions planted in the standard manner showed a close agreement in the number of coliforms found. Moreover the same strains of bacteria were isolated by the concentration method as were obtained with the standard procedure.

After the cultures obtained by the above described methods had been purified, they were examined for Gram reaction. Impure cultures were replated. Cultural, physiological, and fermentation characters were obtained and a tentative identification made. It was found that with these methods it was frequently possible to obtain organisms belonging to the genera *Salmonella*, *Eberthella*, *Shigella*, *Pseudomonas*, *Proteus*, and *Alcaligenes* as well as atypical coliforms. It is not clear what relationship these forms bear to the pollution of the water. After a careful study of many strains which appeared to be *Salmonella*, *Eberthella*, or *Shigella* the results indicated that they were in reality a typical forms of *Proteus*. There were many forms which we were unable to identify by our present system of classification. Dr. P. R. Edwards, of the Department of Animal Pathology, Agriculture Experiment Station, University of Kentucky, kindly assisted with the identification of the suspected *Salmonella* strains. In one instance a culture of *S. aertrycke* was isolated from a dead end sample taken from a Cincinnati water tap. On several occasions *S. oranienburg* was isolated from raw water of Royal Spring, the source of supply for Georgetown, Ky.

Cultures which gave a neutral reaction on Russell's double sugar or Krumwiede's triple sugar tubes were at first discarded as being *Alcaligenes* and unimportant. Later work indicated that these cultures were frequently a variety of *Pseudomonas*. It was found that very often cultures of *Pseudomonas* were present which failed to give the fluorescing character used for identification. Special methods were devised for identifying these strains but this work as yet is incomplete. All cultures which gave neutral or alkaline reactions on Russell's or Krumwiede's were subcultured on synthetic dextrose agar slants. *Pseudomonas* on this medium gives an acid slope with a neutral butt. Most cultures produce a fluorescence when grown in synthetic asparagin broth containing mannitol. Thus far all of these strains have been citrate positive and indole negative.

In epidemics of this type it is of major interest to find out whether any of the organisms present in the water supply appeared as the predominant organism or in any considerable number in the stools of gastro-enteritis cases which had used the supply. Where possible stool specimens were obtained and examined microscopically and smeared on plates of selective media such as MacConkey's agar, desoxycholate citrate agar, *Bacto-Shigella-Salmonella* agar, and bismuth sulfite agar. Suitable portions of the stool were placed in selenite F for enrichment and the growth streaked on the selective media. Suspicious colonies were fished to Krumwiede's triple sugar tubes and those showing a neutral reaction thoughout, or a neutral slant and acid butt, with or without gas, were further identified by cultural, physiological, and serological characters.

Small outbreaks involving a limited number of persons, or families, drinking water from a polluted well or cistern, or involving some institution on a private supply are probably not uncommon. These would not ordinarily come to the attention of the State health departments.

IV. FINDINGS IN WATER-BORNE GASTRO-ENTERITIS OUTBREAKS

Three outbreaks were brought to the attention of the epidemiologic study unit during the period of active field investigation.

(1) The first occurred in an Indiana town of nearly 9,000 persons early in February 1940. The unit was first informed of the outbreak several months afterward but detailed studies, made by the Bureau of Sanitary Engineering of the Indiana State Board of Health, and summarized in a bureau report of April 29, 1940, were kindly submitted to the unit. A house-to-house canvass of 1,431 persons in the town, soon after the epidemic, showed that 302, or 21 percent, had suffered with nausea, vomiting, or diarrhea between February 1 and 5. The figure 1,431 includes 271 persons obtaining their drinking water from wells, cisterns, and other independent sources. As none of these latter persons reported an attack, the incidence rate for the remainder, using town water, was nearly 26 percent. This locality obtains water from a river, at a point 30 miles downstream from a town of 10,000 inhabitants. A prolonged cold spell had converted the river at low stage into an ice-covered conduit. Toward the end of January several million gallons of strawboard-waste had broken through an embankment into the river above both towns, suddenly and tremendously increasing the chlorine demand and contributing undesirable tastes and odors. Chlorine dosage was not increased sufficiently to cover the chlorine demand of the water in the town experiencing the outbreak, and repairs to filters were in progress, permitting turbid water to get into the mains on more than one occasion. A probable explanation, then, was that nearly untreated sewage-polluted water was used for drinking.

Other towns using surface water still farther downstream suffered progressively milder outbreaks at successively later dates, but towns supplied from wells escaped.

This series of outbreaks suggests a small-scale repetition of the series of outbreaks occurring on the Ohio River in the winter of 1930–31 and described by Veldee (1).

(2) On November 18, 1940, the Division of Sanitary Engineering of the Kentucky State Health Department invited the collaboration of the water-borne disease unit in the study of an outbreak characterized by nausea, vomiting, cramps, and diarrhea in the city of Georgetown, Ky. A detailed report of this outbreak is contained in appendix II. This epidemic was studied early, under very nearly ideal conditions of observation, and revealed an epidemiological pattern with which other outbreaks observed in the study and culled from the literature have conformed.

First, the onset of the epidemic was explosive and the duration short.

Second, the incidence among persons using private well and cistern water for drinking was much lower than that among persons using the city supply.

Third, the age and sex distribution of cases in a canvassed population was nearly uniform, indicating that there is no increment of immunity in a population with age or occupation.

Fourth, there was a definite incubation period of 36–72 hours, suggesting an infectious, as distinct from a toxic, etiology.

Fifth, explosive gas formation in standard lactose broth was noted in the 48-hour reading of numerous water samples taken early in the course of the outbreak but this, with the exception of one sample, failed to confirm for coliforms.

Sixth, stools of patients, extensively studied with reliable media, failed to show a common etiological agent.

In detailed studies of all but one of the early water samples and from a limited number of stool specimens, organisms identified as a species of *Pseudomonas* were isolated and hopes were entertained of this being shown as a causal factor. However, more extensive experimental study of three human volunteers with this and other strains did not confirm these hopes. The finding, however, warrants mention as no other organism was found common to both stool specimens and water samples from this outbreak.

The source of supply, the Royal Spring, was found to be subject to more or less extensive pollution—particularly after rains. Treatment (coagulation, filtration, and chlorination) was found to be inadequate. The settling basins were heavily lined with blue-green algal masses (oscillatoria) and dead masses floated on the surface, adding to the organic load and possibly contributing both a tint and a taste to the treated water.

No explanation was found, however, for the comparative freedom from pollution, as evidenced by standard tests of the treated water for coliform bacteria at the time the early samples were taken.

(3) Early in March 1941, the water-borne disease study unit was invited by the Ohio State Health Department to participate in a study of an outbreak closely resembling the Georgetown epidemic, in the village of Navarre, Ohio. A detailed report of this outbreak is contained in appendix III. As this occurrence was nearly over before it came to official notice, no stool specimens were secured. Early tests of the village water by the State health department laboratories revealed the presence of coliforms in 10-milliliter and even 1-milliliter portions. In other respects, however, the outbreak was nearly an exact replica of the Georgetown occurrence noted above.

No evidence of contact transmission could be obtained in house-to-house canvass. Where some in a given home had used the suspected supply and others had not, the infection was always limited to the former. Prolonged pumping of the wells from which the water supply was derived showed very limited numbers of organisms appearing only at the end of the pump run. These organisms were identified as a species of *Pseudomonas*. Coliforms at no time appeared in the samples from the pump, though in samples from some points on the distribution system slow-lactose fermenting organisms and *Pseudomonas* were found. No evidence of pollution at the source, and no point at which pollution entered the distribution system was definitely discovered in Navarre.

The three outbreaks outlined above were the only ones brought to the attention of the unit. The last two were studied under exceptionally favorable conditions and with considerable care. No definite etiological agent was found. However, certain features were ascertained. The outbreaks at both Georgetown and Navarre were quite conclusively proven to be water-borne. An incubation period for water-borne gastroenteritis was established, suggesting an infectious etiology. Finally, a study of stool specimens in one typical outbreak failed to show an etiological agent.

V. LITERATURE ON WATER-BORNE GASTROENTERITIS

A study of previous experience with, and of the literature on, water-borne gastroenteritis was undertaken with a view to amplifying these rather limited conclusions.

A detailed study of this entity by Cox (2) presents a list of hypotheses on the etiology, then a general consideration of a number of outbreaks, as well as a detailed study of a few, and concludes that pathogenic bacteria are usually involved. With his concept that the disease "is in the nature of a mild dysentery" some exception must be taken for reasons which will appear below.

The ensuing paragraphs will summarize briefly a number of references to outbreaks, a few of which were covered by the article of Cox mentioned above. Some of these were gleaned from the valuable publication of Wolman and Gorman (3) and others from various reference sources, as well as from correspondence with persons familiar with the circumstances. Certain details of these outbreaks not mentioned in the text are given in the table in the appendix V when details were available. These include date and day of week of the first cases; duration of outbreaks; date of collection of water samples and interval in days between first cases and first samples; presence or absence of coliforms in first samples; source of water supply, number of persons using the supply, number and percent attacked; and, finally, general remarks on each outbreak. The three outbreaks described in the previous section of this report have also been included in the appendix summary table and will be discussed together with those gathered from the literature.

Although the outbreaks to be described briefly below all bear a strong mutual resemblance in their epidemiological features, they are differentiated into three groups on the basis of certain findings. The first group consists of epidemics of gastroenteritis, apparently water-borne, in which no conclusive evidence of sewage pollution in the

treated water was found by bacteriological analysis, and in which sanitary studies failed to disclose sufficient evidence of pollution of the supply by sewage. The second consists of epidemics with evidence of sewage pollution but without ensuing cases of typhoid fever. The third group consists of epidemics identical with the second except that typhoid fever followed the initial gastroenteritis outbreak.

Group I.—Of the three outbreaks described in the previous section, only that of Georgetown belongs in the first category, and this is possible only because the bulk of evidence indicated surface drainage, rather than sewage, as the most probable means of contamination of the water supply. A search of available sources reveals three others occurring in localities whose water, at the time of testing, met bacteriological standards of potability. These will now be described briefly.

Through the courtesy of the Massachusetts State Department of Health, the records of an outbreak of water-borne gastroenteritis were made available to the unit. This epidemic occurred in Cohasset, Mass., in March 1931, and was studied by one of the authors, then epidemiologist in the Massachusetts State department. Except for the fact that vomiting played a rather more prominent role than cramps or diarrhea, it followed very closely the epidemiological pattern described for Georgetown, of explosive onset, brief duration, uniform age incidence, high attack rate among users of town water only, bacteriologically normal water samples and absence of known pathogens in the stools.

In February 1936 there occurred at Coshocton, Ohio (4), an outbreak similar to those in Georgetown and in Cohasset, no contamination of the system being indicated bacteriologically despite a very definite distribution of cases on the local supply.

The localities so far mentioned have been small cities, towns, or villages, all of which used ground water. One large city, Milwaukee, suffered an outbreak, or a series of outbreaks, which resembled in many respects those outlined above. The most noteworthy one occurred in February 1938 (5). Neither at this time nor in a previous outbreak, in 1936, were confirmed coliforms found in appreciable numbers, though there were elevated total counts and numbers of gas-formers, together with other evidence that water could not be exonerated.

Outbreaks in Georgetown, Cohasset, Coshocton, and Milwaukee occurred with slight, if any, evidence of sewage pollution of the treated water. They had other elements in common, for they occurred in the late fall, winter, or early spring, when the weather was cold. Of the four, only Milwaukee used a surface supply, although the Georgetown supply might be considered of surface origin in that the Royal Spring is apparently fed by surface streams which are subterranean for at least a part of their course. Three of these occurrences show an interesting aggregation of cases during or just after week ends. This fact will be merely noted here and is to be discussed more fully below.

Group II.—Two outbreaks—Navarre and the Indiana town reported above—have already been presented as probably due to sewage contamination but without subsequent cases of typhoid fever.

The literature offers a limited number of examples of known, or putative, sewage pollution outbreaks not followed by typhoid fever. In the group to be discussed the evidence rests upon the finding of

coliforms in all, or at least in a fair proportion of, samples if not upon the actual demonstration of a relationship between the water supply and sewer system.

Another instance was that of the "Tennessee town" (6) with periodic outbreaks in June, July, and August of 1936. Evidence that sewage contamination of the raw water occurred is presented, though the treated water was felt to have been relatively safe.

In Dallas, Tex. (7), a single water main serving about 10,000 persons became polluted and occasioned a severe outbreak of gastroenteritis in April 1937.

In Altamount, N. Y. (8), there occurred a village-wide epidemic of a similar nature in May 1937.

In Vinton, Iowa (9), in February 1938, there was an outbreak of typical gastroenteritis.

Noteworthy is the fact that only three of the six outbreaks in this group occurred in the winter.

In many of the outbreaks discussed in both groups up to this point reference is made to dysentery-like symptomatology along with the gastroenteritis, but only in Cohasset, Georgetown, Altamount, and Dallas was there a record of a definite study of stool specimens and in none of these were possible pathogens found. Typhoid fever, noted above as developing not infrequently after this type of outbreak, was not observed in the wake of any of these epidemics.

Group III.—There are several instances in which typhoid fever did develop after gastroenteritis outbreaks traceable to contamination of drinking water. One of the classic examples is that of the "excursion boat epidemic," reported by Lumsden (10), in July 1912. The succinct account of the gastroenteritis phases of this outbreak is well worth reproducing verbatim:

> From Clinton (including Lyons) about 1,200 persons went on the excursion. Of these persons the writer estimates, from the data collected by Dr. Sugg and himself, at least 600 (or 50 percent) became ill between 12 and 72 hours after their return from the trip. The illness was manifested usually by nausea and vomiting, diarrhea, and prostration. Diarrhea was the most constant symptom. The majority of the cases had nausea and vomiting along with the diarrhea. A few had nausea and vomiting without diarrhea. A small proportion had fever during the diarrheal attack. Some had rather severe abdominal pain. In the majority of cases the duration of the gastrointestinal disturbance was from 3 to 5 days. In some cases the attack continued for only about 24 hours and in others for several weeks. In some of the cases there were recurrences at intervals of 3 or 4 days. The symptoms presented in the attacks were similar to those which have been presented in a number of outbreaks of diarrhea (sometimes referred to as outbreaks of "winter cholera") resulting from the use of water supplies polluted with sewage. Striking examples were furnished by the outbreak in Mankato, Minn., in 1908 (11), and the one in Rockford, Ill., in 1912 (12).
>
> Among the residents of Clinton who did not go on the excursion trip on the steamer *G. W. Hill* on July 29 there was during the summer of 1912 no unusual occurrence of diarrheal disease * * *.
>
> The writer canvassed in Clinton about 50 households, some of whose members went on the excursion. The outbreak was sharply confined to those who went on the excursion. In a number of instances every member of a family who made the trip was attacked and every member of the family who did not go on the excursion was exempt.

This outbreak was considered to have resulted from pumping river water into the steamer's drinking water tank while the vessel was docked over a sewer outlet. Eleven cases of typhoid fever followed the gastro-enteritis.

In January 1924, the city of Santa Ana, Calif. (13) suffered a severe outbreak of gastorenteritis followed by an epidemic of at least 226 cases of typhoid fever. Cases of paratyphoid, dysentery, and paradysentery were also diagnosed.

Detroit (14), in February 1926, had a similarly widespread outbreak which was, however, followed by the comparatively small number of eight cases of typhoid fever.

In the summer of 1926 an extensive outbreak of gastroenteritis, followed by dysentery, paratyphoid and typhoid fever occurred in the urban district of greater Rostov-on-the-Don (15) in Russia. There were 2,978 cases of recognized typhoid and paratyphoid fever in this outbreak.

The Chicago stockyard fire on May 19, 1934, gave rise to a most interesting outbreak, reported by Hardy & Spector (16). While fighting the fire a number of firemen drank polluted water and experienced mild attacks beginning 1 to 3 days later, characterized by nausea, occasional vomiting, and diarrhea. A larger number were reported to have had more intense symptoms lasting for several weeks. Evidence is presented incriminating *Endamoeba histolytica* in this latter type of case. Sixty-nine cases of typhoid fever and two cases of paratyphoid fever were also reported. A useful description of the gastroenteric features of the outbreak is included in this report and a new symptom added to the syndrome—progressive loss of weight. This symptom will be mentioned again below.

An outbreak, carefully studied from the laboratory point of view by Ziegler (17) occurred at Springfield, Mo., early in July 1936. Cases were described as having less uniform symptomatology than in the epidemics just outlined. Organisms not fermenting lactose, or fermenting it slowly, were isolated from water samples and from some of the stool specimens.

In December 1940, an old cross connection was briefly opened in Rochester, N. Y. (18) allowing polluted water from a high-pressure fire-control system to flow into the regular water supply mains. The cross-connection was open from about 4:30 p. m., December 11, to 8 a. m. December 12. More than half the gastroenteritis cases canvassed had onsets on December 13 and 14 and six cases of typhoid fever followed in due course.

It is notable that in this last group of outbreaks, featuring typhoid fever cases, reports of other enteric syndromes such as dysentery and paratyphoid fever are more prominent. In the first two groups discussed—those with no evidence of sewage pollution and those with evidence thereof, but not followed by typhoid fever—much milder syndromes with no mortality and with a greater predominance of gastric symptoms (nausea and vomiting) are detailed.

As noted above more data are available on these outbreaks in appendix V. Information on dates of the beginning of epidemics has been included there because there seems to be a tendency for outbreaks to start on, or very shortly after, a week end or holiday. This was the case in Georgetown, Navarre, Cohasset, Coshocton, Dallas, Altamount, Milwaukee, and in the "Tennessee town" (where week-end outbreaks were noted periodically during the summer). In Milwaukee daily case totals increased markedly on Mondays for 3 successive weeks. Two outbreaks starting in midweek—those in the "Indiana town" and in Rochester—followed repair work on the respective

systems. The implication of this week end and holiday grouping is obvious when it is remembered that even in large cities the operating staff of waterworks is generally reduced at such times and vigilance consequently relaxed.

One outbreak, epidemiologically resembling the milder form described above, has not been included with them because it was attributed to another cause. On May 6, 1939, an epidemic of nausea and vomiting, with or without diarrhea, occurred in one section of Olympia, Wash. (19). Although back-siphonage was found to have occurred at the local school, no bacteriological evidence of pollution was found and the outbreak was attributed to volatile poisons from the painting of a water tank restored to service on May 4. School children were affected primarily and the onsets of cases were noted as occurring in the early morning hours—a rather delayed onset for most chemical intoxications. No mention is made of tastes or odors in the water likely to be associated with volatile chemical poisons.

The European literature has been but lightly considered in the above discussion. Papers by Hornung (20) and by Rimpau (21) describe outbreaks. Kathe and Konigshaus (22) and Knorr (23) also deal with the subject. The study of the Hanover Typhoid Outbreak by Mohrman (24) contains some data on gastroenteritis.

A review of the literature should not be ended without mentioning the stimulating contribution by Schaut (25). This author cites a body of evidence to show that organic cyanides of vegetable origin may be present in water and urges that these be considered as a possible cause for gastrointestinal outbreaks originating from water. Further observations on this will be made below.

The conclusion derived from field work and from a review of the literature on the subject is that waterborne gastroenteritis is a definite infectious entity quite distinct from the dysenteries, paratyphoid, and typhoid fevers. Because it has an incubation period it appears to be a virus or bacterial infection rather than the result of a chemical intoxication. It should be noted, however, that there is theoretically a hybrid between the infectious and toxic hypotheses which cannot be ruled out on the basis of this reasoning: Quite possibly the ingestion of water containing an organism capable of rapidly producing hydrogen sulfide, cyanide, or one of several amines, or other decomposition products in the intestinal tract, could produce a syndrome of this sort.

The disease is not readily communicable from person to person by contact. The varied symptomatology suggests a complex of infections rather than a single type, but this variation in symptoms may be the result of variations in dosage, or of idiosyncrasy. The etiological agent, or agents, have not been identified. The findings in Springfield, Mo., are suggestive but have not been confirmed in other outbreaks.

That the disease is spread by water and often by sewage pollution of water is definitely established. However, there is room for some doubt as to whether sewage contamination is the sole source of the infection, in view of the occasional instances in which no such pollution could be demonstrated. The experience in the field and a review of the literature leave but two deductions on this point: Either (*a*) sewage pollution is a common but not an only source, or (*b*) the bacteriological standard, with its heavy emphasis on coliform detection, is not an infallible index of water conditions affecting the prevalence of

gastroenteritis. Both points of view will be found expressed in the literature and both may, of course, be correct.

As some of the laboratory studies conducted by the unit bear upon these questions, they will be discussed after these studies have been presented in the next section.

VI. EXPERIMENTAL LABORATORY FINDINGS

Because outbreaks were few in number and because several leads were obtained in the course of field work, laboratory studies were carried out. Among the most pertinent of these were observations upon the effect of Berkefeld-filtered sewage taken orally by human volunteers.

1. *Experiments with Berkefeld-filtered sewage.*—Fresh human sewage from a sewer pipe draining a populous hillside in Cincinnati was used for these experiments.

The first experiment was carried out with a single volunteer who drank 250 milliliters of sewage filtered through a Berkefeld N filter. The filtrate was clear, contained fewer than two coliforms per 100 milliliters (no gas formation at 48 hours at 37° C. in five 10 milliliter portions planted in lactose broth and the number of bacteria growing on plates after 48 hours' incubation was about five per milliliter); Gram stain of the sediments in the lactose broth tubes revealed only Gram-negative elements—chiefly *Pseudomonas* and vibrioid organisms. However, a small spirochaete was also detected by dark-field examination and found to be the most abundant organism in the filtrate.

Thirty-two hours after taking this filtrate the volunteer developed a profuse watery diarrhea lasting 18 hours, and a few hours after this began he became nauseated and retched without actually vomiting. Temperature was normal or subnormal at the start and rose to 101° F. after a considerable period of diarrhea with dehydration. Extensive examination of four stool specimens upon a wide variety of media revealed no significant organism. A rather surprising finding after recovery was a progressive loss of weight from 180 to 170 pounds in the ensuing 10 days.

Reexamination of the sewage filtrate after being stored in the ice box at 40° F. for 48 hours revealed a twentyfold increase in the bacterial count which was largely due to proliferation of *Pseudomonas*. Some strains of this genus are known to be cryophillic.

Three months later another lot of sewage was filtered through two Berkefeld N filters and ingested by four volunteers—one of them the original recipient of the material described above. Filtration was less efficient this time, filtrates from both filters showing a most probable number of 13 coliforms per 100 milliliters and a count of 160 bacteria per milliliter at 48 hours. Color-producing *Pseudomonas* were detected in one filtrate but none was isolated from the other, though organisms with similar cultural characters without color production were obtained from the latter. Vibrioid organisms were not found but spirochaetes were abundant in both samples. As in the previous experiment, the only other organisms found in these filtrates were Gram-negative.

Two volunteers drank 250 milliliters and 50 milliliters, respectively, of one filtrate and two received similar amounts of the second. The original volunteer experienced an attack identical with the one he

experienced in the first test, even to the length of the incubation period. His weight loss subsequently was, however, more marked (15 pounds). Another volunteer was nauseated and vomited twice after a 34-hour incubation period. The other two experienced nausea and diarrhea, with malaise, abdominal cramps, and constant, dull abdominal pain for 12–18 hours. One of these last also showed a progressive weight loss during the period following convalescence. Spirochaetes, very similar in appearance to those found in the lactose broth cultures of filtrates, were observed in one freshly passed stool. No known pathogens were detected upon extensive study of stool specimens from these patients.

A final experiment was performed with six volunteers drinking from 50 milliliters to 250 milliliters of sewage filtered first through a Berkefeld N and then through a Berkefeld W filter. The filtrate produced no visible growth in lactose broth tubes at 48 hours and was considered virtually sterile. It remained in the ice box during this period and was taken by the volunteers only after this fact had been ascertained. Five volunteers showed no effects, but the sixth, who had received only 50 milliliters, developed marked nausea and a mild diarrhea without fever after an incubation period of 48 hours. Samples of the filtrate used in this experiment planted in lactose broth developed a faint haziness on the third day, and by the sixth it was evident that all of the six 10-milliter and three out of six 1-milliliter portions contained either vibrioid organisms, or spirochaetes, or both. *Pesudomonas* was not found in this filtrate.

The information furnished by these data on the causative agent of the disease is fragmentary and inconclusive. The spirochaete was the only organism consistently found in all the filtrates, and the possibility that it was responsible was, perhaps, the best lead obtained. Such an organism would not be expected to develop on the agar media ordinarily used for isolation of intestinal pathogens, thus accounting for the failure to find causative agents in stools. The incubation periods observed are, however, very short for a spirochaetal disease.

In this connection it should be noted that Kathe (26) and Prausnitz & Lubinski (27) have described an entity, designated "Schlamm fieber," with an incubation period of very short duration to which a spirochaetal etiology is ascribed. Wolter (28) endeavored to attach this diagnosis to the gastroenteritis preceding the Hanover outbreak.

While these experiments failed to reveal the responsible agent they are of considerable importance for they reproduced in the laboratory, under somewhat controlled conditions, attacks very similar to those witnessed in the field—and the filtrates, it will be noted, showed variations quite comparable to those encountered in the field so far as coliform tests were concerned. They support the field experience that sewage contains an agent giving rise to gastroenteritis which is not ordinarily isolated on the media commonly used for the study of enteric disease. Unless the 48-hour period of retention of the material of the last experiment in the ice box destroyed infectious or chemical elements, these experiments also disprove the virus as well as the chemical theory of etiology. Finally, they indicate that the agent responsible for at least one form of gastroenteritis may be considerably more filterable than the coliforms used as an index of sewage pollution.

More intensive studies of sewage filtrates and of their experimental effects are clearly desirable.

2. *Experiments with Pseudomonas.*—Certain experimental studies were also made upon strains of *Pseudomonas* encountered in the field and laboratory studies above described. Methods of quick isolation and identification of *Pseudomonas* strains were evolved. These organisms grow readily on most of the media used for stool examination and water analysis. Streaked on nutrient agar, the green or blue color production was found to be inconstant after incubation at 37° C. but to be quite dependable when incubated at 20°, or when 37° cultures were left for a few hours in the ice box. Upon opening closed Petri-dish plates containing cultures of several strains, a distinct odor of cyanide was often observed, and amounts of cyanide up to 0.6 parts per million were removed from broth cultures growing under partially anaerobic conditions by the methods outlined by Patty (29). It is not impossible that at least some of the cyanide noted by Schaut (25) in waters may be derived in part from this ubiquitous organism.

LaCorte (30) has stated that filtrates of gelatin cultures of *Pseudomonas pyocyanea* produced death with bloody diarrhea when injected introduodenally into animals.

In the laboratory studies which follow, filtrates of lactose broth and of gelatin cultures of *Pseudomonas* strains were taken orally on an empty stomach by three human volunteers. Subsequently whole cultures containing several millions of organisms were also taken in the same way by two of these volunteers. No nausea, vomiting, diarrhea, or cramps were noted in these experiments with whole cultures.

When filtrates of cultures are taken in amounts from 5 to 20 milliliters in 50 to 100 milliliters of water, a definite local anaesthesia of the tongue, fauces, and pharynx is noted which persists for several hours. There is a transient feeling of epigastric soreness. For 1 or 2 days after the ingestion stool specimens, streaked on MacConkeys agar, may show little or no growth (even when heavy innocula are used).

When whole cultures of *Pseudomonas* are ingested the organism may or may not appear in the subsequent stools. These frequently showed, however, the same relative lack of growth on MacConkey's agar that was noted in experiments with filtrates. When *Pseudomonas* was recovered from the stool it was quite likely to be in pure culture at first, gradually being replaced by coliform colonies in subsequent stools. The incompatibility between *Pseudomonas* and coliforms in common culture is not limited to the human intestine. *Pseudomonas* cultures are known to exert a bacteriostatic, if not actually a lethal, effect, upon many other bacteria in vitro. West (31) has suspected a limitation of the standard bacteriological test for coliforms where *Pseudomonas* organisms occur as contaminants with coliforms in water samples on this basis. The subject merits further study.

3. *Clostridium Welchii Toxin*. Because *Clostridium welchii* was once suggested by Nelson (32) as a cause of diarrhea and because of the late gas formation noted in Georgetown water samples, experiments were conducted with four specimens of *Clostridium welchii* toxin kindly forwarded by the National Institute of Health. Amounts of each up to 40 milliliters, diluted to 100 milliliters with distilled water, were taken by mouth by a single human volunteer without notable gastrointestinal effects.

4. *Algal toxicity.*—Blue-green algae have recently been recognized as contributing more than tastes and odors to water. Fitch, et al. (33), have emphasized their importance from the point of view of domestic animals. Strell (34) notes the production of cyanide by blue-green algae as a matter of common knowledge, but unfortunately gives no basis for his belief.

Studies of some of the more common blue-green algae were accordingly begun. None was found to have any toxic effect when given to animals by mouth. One—*Microcystis aeruginosa*—was repeatedly found to be lethal for mice and guinea pigs when injected parenterally. The toxicity was greatly increased when the algae were frozen, or frozen and dried in vacuo, for preservation. The toxic substance could be dialyzed and withstood autoclaving so that it was considered to be a chemical poison rather than a bacterial toxin. Dilute solutions remained toxic after coagulation with alum, settling, laboratory filtration, and chlorination, but when comparatively large amounts of carbon were used as an adsorbent the solution was detoxified. When the toxic substance was partially purified and administered parenterally to mice the lethal dose was found to be comparatively small—0.4 mg. Cyanides were at no time detected in algal material.

VII. SUMMARY OF FINDINGS ON WATER-BORNE GASTROENTERITIS AND DISCUSSION

The studies of the unit have added their quota to the evidence that a form of epidemic gastroenteritis is actually water-borne; that there is a definite incubation period of 30 to 48 hours; that the condition is an infection, not an intoxication; and that such outbreaks may occur with little or no evidence of sewage pollution by standard bacteriological tests of water applied within 5 days of the time such pollution must have occurred. They have shown that the symptomatology and epidemiology of at least one outbreak with no evidence of sewage pollution were indistinguishable from one in which evidence of such pollution was found.

The experiments with Berkefeld-filtered sewage have revealed a syndrome in human volunteers which is indistinguishable from that encountered in the field studies of outbreaks. The fact that a careful search was made for accepted pathogens on an assortment of media, and that none were found, clearly indicates that one or more unrecognized organisms may be responsible.

Less conclusive, but highly suggestive, were two other findings from the review of the literature and of the outbreaks observed by the unit: A tendency for outbreaks, where sewage pollution could not be demonstrated, to occur in the late fall or winter months and a tendency for outbreaks to occur after week ends or holidays when not directly related to repair work on the water treatment or distribution systems.

Inference, duly labeled as such, is more often required in the interpretation of observations on human experience than of purely laboratory findings, because the observation of human experience can seldom be controlled adequately or completely. When the shortage of supervisory staff in most waterworks on holidays and week-ends is considered, it is not difficult to supply an inference for the aggregation

of outbreaks at such times. The maintenance of a high quality of treatment and of uniform distribution cannot be left to automatic controls or to half-staff supervision.

Several questions are raised by the other observations for which solutions can only be provided in the form of hypotheses. The occurrence of outbreaks without evidence of recent sewage pollution brings out the question contained in the deductions mentioned at the end of section V: Does the agent of water-borne gastroenteritis exist elsewhere in nature than in human sewage, or is the bacteriological test for coliforms less indicative of pollution that may give rise to gastroenteritis than is generally believed?

In this connection a hypothesis can be formulated to explain the various observations noted above in the field studies of the unit and in the reports of others who have explored the subject. A study of the months of onset of outbreaks shows that where the outbreaks resulted from polluted water they occurred either in winter or in summer. The limited number of coliform-negative outbreaks all occurred in cold weather. The numbers are small in both instances and definite conclusions cannot be drawn. However, there seems a possibility that in cold weather coliforms occasionally may be replaced rather rapidly after they gain admission to water mains by hardier forms which, alone, are found by the time samples are collected and analyzed. With a 1- to 3-day incubation period before gastroenteritis supervenes and a 1- to 3-day period before investigation is begun, this hypothesis could explain the occasional absence of coliforms in collected samples, if it were known that other organisms found in sewage can displace or overgrow coliforms under conditions of "cold storage." Reports on this subject are rather few but some are suggestive. Parr (35) cites a citrate-utilizing slow lactose fermenting coliform capable of rapidly displacing other types of coliforms in feces stored in the ice box. That certain strains of *Pseudomonas* do grow readily at low temperatures is well known. The cultures and filtrates of cultures of some of these latter organisms are known to have a bacteriostatic, if not an actual lethal, effect on other microorganisms, and indications are not lacking (31) that the presence of this organism may prevent the identification of coliforms in the standard presumptive coliform tests. Studies at present under way (36) indicate that a considerable preponderance of *Pseudomonas* is needed to achieve complete suppression of gas formation, and it may be doubtful whether such a preponderance could have been achieved in the water mains during the short period before the Cohasset, Georgetown, and Coshocton outbreaks came under study.

The above hypothesis is a rather tenuous one but offers some grounds for detailed studies in view of the implication it carries as to the fallibility of the standard bacteriological test to demonstrate pollution in the recent past under cold weather conditions.

According to this view the standard coliform test, if applied at the time of pollution, would still suffice, but cannot be relied upon indefinitely, particularly in the presence of certain other organisms.

What supplementary tests might be employed in the occasional instance where pollution cannot be demonstrated by standard methods? The laboratory studies suggest two organisms that might be regarded with suspicion until further work exonerates them or implicates one, or both, more definitely—the *Pseudomonas* and the spiro-

chaete. Both are apparently present in sewage; both survive fairly drastic filtration.

The above supplementation is not necessary for routine analyses of water quality and is suggested simply as an adjunct of epidemiological study in the rare instances where routine methods fail. Such failure would appear to be due to delayed application rather than to inadequacy.

The implication from the week-end onsets of outbreaks is that present filtration and chlorination standards are adequate for the control of water-borne gastroenteritis from polluted sources if these standards are consistently met.

VIII. STUDIES OF DIARRHEA AND ENTERITIS

As stated in the first section of this report, a further aim of the unit was to determine to what extent the source and quality of the drinking water of communities might contribute to the prevalence of "diarrhea and enteritis," commonly confused with the syndrome described at length in the preceding sections.

For this purpose 144 cities of 10,000 or more population throughout the Ohio River Basin were selected. As complete morbidity data for diarrhea and enteritis are nonexistent, mortality data were selected to serve the ends of the study. The annual mortality statistics (37) volumes served as the source of these data. For each of the cities, deaths under the following rubric were taken off for the years 1900–1937:[1]
"All causes," "Diarrhea and enteritis" (for all ages, and specifically under 2 years) and "Typhoid fever." In order to obtain annual rates of mortality, population figures for each city were obtained from the decennial census volumes, simple linear interpolation being used to obtain population in intercensal years. Because there were wide fluctuations, particularly in the "Diarrhea and enteritis" rates for a given locality from year to year, 5-year median rates were derived for certain purposes.

Where rates are used as indices of variation, it is customary to apply corrections in order to eliminate effects incidental to the chief cause of variation. Differences with respect to age, sex, and color were studied in sample cities and found to involve minor corrections, if any. On the other hand relatively important corrections were indicated in many cities on the basis of residence. Many of the larger cities tended to accumulate patients from surrounding rural areas or nearby smaller cities (hereafter called "satellite cities") with the result that rates for the former were unduly high. In the satellite cities of the study, on the other hand, rates were often unduly low—sometimes actually zero for quite long periods. The residence death correction could not be made specifically for diarrhea and enteritis deaths—no such data being available—but was based upon deaths from all causes from 1937 and 1938 "mortality statistics" data on resident and nonresident deaths from all causes in each city.

It is recognized that the rubric "diarrhea and enteritis" is so comprehensive that a subclassification would be highly desirable. It probably includes a great many conditions quite incidental to infectious, or even to noninfectious, conditions of the intestinal tract and

[1] Certain cities attaining their 10,000 "majority" after 1900 were included where data over a sufficient interval could be obtained.

it does not include all dysentery deaths, which would be highly pertinent to the investigation at hand. However, deaths specifically classed as dysentery were so few that their omission from the rates was found to make unimportant changes, and this item was accordingly omitted. Actually most of the severe or fatal cases classed as "Diarrhea and enteritis" have been found to be undiagnosed dysentery. One of the important causes of diarrheal death in the South is probably undiagnosed pellagra—a point which should be carried in mind when the relatively high rates in this region are being considered. However, dysentery deaths are also more frequent in the South than in the North and undoubtedly still constitute the bulk of the deaths from diarrhea and enteritis.

The method of the study consisted in comparing the rates for groups of cities, each group differing with reference to some important aspect of water source or treatment. Comparison was also made between typhoid fever and diarrhea and enteritis rates in order to determine whether the installation of various improvements in water treatment might have affected one more than the other. Finally certain detailed studies were made of water quality in relation to diarrhea and enteritis mortality in individual communities.

In general, there are two sources of urban water supply—well water, hereafter called ground supply, and surface water from streams, creeks, and rivers. Many cities, however, have both, using one or the other as supplementary source or continuously use the two in combination. Enough cities used these combined supplies to warrant a third category hereafter referred to as "mixed supply."

TABLE 1.—*Averages and medians of the 1933–37 mean diarrhea and enteritis death rates per 100,000, of cities in the Ohio River Basin, as a whole and by regions, according to source of water supply*

Area	Surface	Mixed	Ground
	A. Averages of mean rates		
Total, Ohio River Basin	21.6	14.3	19.0
Northeast	12.3	11.1	11.3
Northwest	26.4	19.8	22.5
South	39.0	28.4	33.5
	B. Medians of mean rates		
Total, Ohio River Basin	13.7	15.4	16.0
Northeast	11.6	10.4	11.2
Northwest	20.3	18.7	21.3
South	33.0	28.4	35.8

For a comparison of rates in cities using these three categories of water, the annual rate for diarrhea and enteritis for each city over the period 1933–37 was derived, and the mean rates for all the cities in each group were averaged to obtain a mean rate for the group. The comparison is shown for cities in the Ohio River Basin in the first line of table 1.

The variation between rates in individual cities of the basin is very marked. It is often quite extreme when the rates for adjacent cities are compared. This subject will be discussed at greater length below. However, in general, the rates tend to be lowest in the northeastern section (southern New York, western Pennsylvania, eastern

Ohio). They become higher in the northwestern section (western Ohio, Indiana and eastern Illinois) and tend to be very high in the southern section (West Virginia, Kentucky, Tennessee, northern Alabama). Ground-water supplies are more frequently used in the two northern sections and surface water supplies more commonly in the South. There is, however, a fair number of both in each of the regions so that a regional comparison would appear to be indicated. This has been made in the next three lines of table 1. Here, only a slight excess mortality appears in the cities using surface supplies when compared with those using mixed or ground supplies. The variation by region is seen to be quite striking—averages for the Northwest and for the South being about double and triple, respectively, those for the northeast in each category. Mixed supplies tend to show lower rates than either ground or surface, but there are relatively few of these.

Because even the mean rates for cities over a 5-year period show rather wide variation, the median offers perhaps a better basis for comparing these rates than the average. The second part of table 1 shows median data for the same groups of cities. Here very little difference appears between the various sources of supply; the basic difference is again unquestionably the regional one.

Ground-water supplies in general are considered less subject to pollution than surface supplies. Like all generalizations, this has its exceptions, but it holds true.

A further study, supplementary to the above, was made of the variation in mortality from diarrhea and enteritis, with variation in the quality of raw water for cities using surface supplies. The diarrhea and enteritis deaths in individual cities were compared with the monthly average figures for the most probable number of coliforms, and plate counts, in the raw water of individual cities using surface water as a source of supply over a considerable period of years. Such data were available for Cincinnati, Ohio, and for Louisville, Ky. In general the coliform most probable number and plate counts tended to run low in the summer and higher in the winter in the raw water of both of these cities, while the diarrhea and enteritis deaths were concentrated in the summer months and declined notably with the onset of cold weather. On a monthly basis, therefore, no definite relationship could be found between the quality of the raw water as indicated by the most probable number of coliforms and the plate counts.

A final comparison—that based on the quality of treated water—would be perhaps more pertinent to the present study. However, very nearly all of the 144 cities consistently met the United States Public Health Service standard over the period 1933–37 and little basis therefore exists for the establishment of subdivisions based on treated water quality. A majority of cities also used equipment and techniques of water treatment of a sufficiently high order so that grading them upon such a basis would entail division into groups differing in such minor respects as to be unimportant.

One of the early proofs that typhoid fever in cities was traceable to polluted water supplies, was obtained by the demonstration of consistently, and often strikingly, low rates following the installation of water treatment procedures, such as filtration and chlorination. Typhoid-fever death rates prior to and subsequent to the water treatment installation formerly were compared and decreases in the latter as compared with the former were noted with enthusiasm.

The same favorable effect was often discernible in the death rate for all causes (Mills-Reinecke phenomenon). The effect on the typhoid-fever rates was often definite and unmistakable. The effect on the general death rate was less clear-cut, and it was soon recognized that, where a rate was consistently declining—as the general death rate from all causes was declining in most cities during the latter part of the nineteenth and in the early part of the twentieth centuries—some decrease inevitably occurred when the rate for a later period was compared with that for an earlier period.

The effect of the installation of improved water-treatment methods on the typhoid-fever death rate seemed definite enough, however, to provide a gage for the extent in which diarrhea and enteritis deaths may have been, to former years, ascribable to water. With this in view, three groups of cities using surface-water supplies and beginning water treatment in the interval 1905 to 1933 were studied in detail. The first group consisted of seven cities (table 2) instituting filtration and chlorination in combination. The second contained 14 cities (table 3) where filtration was started independently of, and usually prior to, chlorination. The third contained 22 cities (table 4) where chlorination was begun independently of, and usually subsequent to, filtration. Groups 2 and 3 contain many cities in common. Diarrhea and enteritis mortality rates were computed for individual years for the 5 years preceding and the 5 years subsequent to the installation of treatment (omitting the year in which treatment was begun). Because the diarrhea and enteritis rates show a consistent downward trend over the whole interval 1900–37 it was to be assumed that the subsequent interval would show lower rates whether water treatment was related to diarrhea and enteritis mortality or not. As a control, similar rates for typhoid-fever mortality were computed for comparison with those of diarrhea and enteritis.

Averages of the-5-year annual rates for the periods before and those after installation were at first used, but variability in these intervals prompted the use of the median rather than the mean. Both methods were in essential agreement, so the median rates were selected for presentation. The resulting tables show the median diarrhea and enteritis and typhoid fever mortality rates for the two intervals before and after beginning treatment as follows: Table 2, cities beginning filtration and chlorination in combination; table 3, cities instituting filtration separately; table 4, cities instituting chlorination separately.

TABLE 2.—*Median mortality rates per 100,000 for typhoid fever and for diarrhea and enteritis for the 5-year periods before and after combined filtration and chlorination in 7 cities using surface supplies*

City	Diarrhea and enteritis			Typhoid fever		
	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before
Logansport, Ind	70.3	34.4	0.49	37.9	34.0	0.90
Cambridge, Ohio	50.0	39.8	.80	40.3	7.8	.19
East Liverpool, Ohio	104.2	61.0	.59	76.6	32.8	.43
Ironton, Ohio	93.9	45.5	.48	65.9	13.0	.20
Portsmouth, Ohio	94.1	90.5	.96	70.9	28.3	.40
Steubenville, Ohio	156.3	143.0	.92	67.8	22.0	.32
Wilkinsburg, Pa	93.3	35.0	.37	47.6	18.0	.38

TABLE 3.—*Median mortality rates per 100,000 for typhoid fever and for diarrhea and enteritis for the 5-year periods before and after filtration in 14 cities using surface supplies*

City	Diarrhea and enteritis			Typhoid fever		
	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before
Anderson, Ind	91.1	68.9	0.76	72.7	28.1	0.39
Evansville, Ind	87.3	75.1	.86	34.1	23.6	.69
Indianapolis, Ind	123.2	73.4	.59	43.5	31.3	.72
New Albany, Ind	60.9	53.9	.89	23.4	18.1	.77
Louisville, Ky	72.8	52.0	.72	63.6	26.7	.42
Paducah, Ky	203.2	81.5	.40	85.2	65.3	.77
Bellaire, Ohio	110.5	48.5	.44	36.2	20.5	.57
Cincinnati, Ohio	109.2	99.9	.91	61.2	13.3	.22
Columbus, Ohio	60.1	55.2	.92	35.8	18.8	.52
Marietta, Ohio	52.8	53.6	1.02	98.0	23.1	.24
Youngstown, Ohio	115.9	169.9	1.47	123.7	36.3	.29
McKeesport, Pa	196.8	159.4	.81	107.1	32.5	.30
Wilkinsburg, Pa	93.3	46.2	.50	47.6	34.0	.72
Nashville, Tenn	55.1	35.8	.65	16.1	7.7	.48

It will be observed that the 5-year median rates for cities in the first group (table 2) uniformly fell for the interval after the treatment as compared with those for the period before treatment. However, the decline was not as marked (as shown by higher ratios) as in the case of typhoid fever.

The same is true of tables 3 and 4 although here, occasionally, higher median rates for both diarrhea and enteritis and typhoid fever are evident in the post-treatment interval.

TABLE 4.—*Median mortality rates per 100,000 for typhoid fever and for diarrhea and enteritis for the 5-year periods before and after chlorination in 22 cities using surface supplies*

City	Diarrhea and enteritis			Typhoid fever		
	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before	Median—1 to 5 years before	Rates—1 to 5 years after	Ratio—*after* before
Evansville, Ind	75.1	32.2	0.43	23.6	4.5	0.19
Indianapolis, Ind	73.4	68.0	.93	31.3	24.0	.77
New Albany, Ind	53.9	38.7	.72	22.2	4.3	.19
Terre Haute, Ind	111.8	83.2	.74	37.1	24.4	.66
Vincennes, Ind	75.1	54.0	.72	25.4	24.4	.96
Louisville, Ky	52.0	50.2	.97	24.0	14.4	.60
Paducah, Ky	81.5	76.4	.94	60.5	24.8	.41
Asheville, N. C	58.7	48.3	.82	18.3	7.6	.42
Bellaire, Ohio	116.1	47.6	.41	20.5	7.0	.34
Cincinnati, Ohio	110.3	77.1	.70	13.3	6.6	.50
Columbus, Ohio	47.6	38.0	.80	13.9	4.5	.32
Marietta, Ohio	28.5	33.5	1.17	29.9	20.4	.68
Newark, Ohio	42.9	44.4	1.04	35.1	7.4	.21
Springfield, Ohio	41.6	30.3	.73	26.2	6.4	.24
Warren, Ohio	49.0	73.9	1.51	28.6	33.3	1.16
Youngstown, Ohio	14.2	8.3	.58	1.2	1.2	1.00
Beaver Falls, Pa	133.6	103.5	.78	16.7	40.8	2.87
Du Bois, Pa	80.4	40.2	.50	14.7	7.6	.52
McKeesport, Pa	159.4	82.7	.52	32.2	10.8	.34
New Castle, Pa	124.0	83.7	.68	48.4	21.7	.45
Uniontown, Pa	79.6	81.3	1.02	97.7	59.1	.61
Wilkinsburg, Pa	68.7	35.2	.51	45.7	18.0	.39

Mean ratios for diarrhea and enteritis in the three groups are 0.66, 0.72, and 0.78, respectively. This means that the median rates subsequent to treatment were between two-thirds and three-quarters of the median rates prior to treatment. Typhoid fever, on the other hand, shows more consistent decreases. Here mean ratios for the three groups were, respectively, 0.40, 0.51, and 0.63. A review of the ratios, city by city, will show that marked decreases in the diarrhea and enteritis rates (as shown by low ratios) are not necessarily accompanied by similar decreases in typhoid fever and vice versa.

The tentative conclusion is that improvement in the safety of drinking water by water treatment in cities of the Ohio River watershed did not affect the diarrhea and enteritis mortality to the extent that these improvements affected the typhoid fever mortality. A detailed study of trends would be needed to establish this point more definitely. The era in which these improvements were begun (largely between 1905 and 1925) was one of great activity in environmental sanitation generally. Water treatment was but one of these activities; simultaneously privies were abolished with the extension of sewage systems, garbage was collected and burned or buried, livery stables disappeared, and foods were safeguarded.

Limited as the foregoing observations have been to diarrhea and enteritis mortality, they do not rule out the possibility of a considerable morbidity with low mortality in cities with water as the vector. They simply indicate that the mortality listed under the rubric "Diarrhea and enteritis" is but little influenced in recent years by the source of the water supply when adequate treatment is applied.

These essentially negative mortality findings would be more conclusive if real relationships with other sources or vectors could be demonstrated. Other relationships were sought and suggestive leads were found, though no definite conclusions were drawn.

Forming, as dysentery does, a notable proportion of the severe deaths attributed to diarrhea and enteritis and being, as dysentery is, a disease of poverty, it might be expected that economic factors are of importance in the distribution of diarrhea and enteritis deaths. Such a hypothesis might well be evolved to explain the prevalence of this group of diseases in the South, and in the crowded sections of the larger cities. However, no clear-cut relationships between diarrhea and enteritis death rates, city by city, and various economic indices (income-tax payments, magazine sales, etc.) could be found.

Very definite was the relationship between latitude and diarrhea and enteritis mortality for cities in the Ohio River Basin. A subsidiary relationship here was found to be altitude. With few exceptions cities located at higher altitudes enjoyed more favorable rates than those at lower altitudes but in the same latitude. This factor was found to explain some, but not all, of the variation between neighboring cities.

These findings suggested that climatic factors may be of importance. A very considerable and conflicting literature on the relationship of diarrhea and enteritis mortality and climate exists, which will not be possible to review here. The studies of the unit on climate in relation to diarrhea and enteritis covered a wide variety of localities. It was noted that diarrhea and enteritis deaths when studied for individual States, by months, tended to show fairly narrow, elevated peaks in the late summer (August and September) in the northern

States, while the peaks came earlier (May–June) in the southeastern States and tended to have a broader base. In the States of the continental United States precipitation is fairly constant throughout the year but temperature varies markedly. The reverse is true in Puerto Rico and Hawaii where temperature remains throughout the year at levels reached only in summer in the United States but where rainfalls vary considerably. In Hawaii the rains, according to rather fragmentary data for Honolulu, occur in what would be the winter months. In Puerto Rico there are two periods of rain, one in summer and one in winter. Diarrhea and enteritis mortality is surprisingly high throughout the year in both these localities but small peaks of mortality frequently occur after the rains—which are seldom excessive. The relationship is not a direct one because the mortality maxima tend to follow the peaks of rainfall after an interval of a month or more and do not coincide with them.

When the climatic and monthly mortality record of individual cities of the Ohio River Basin is studied over a long time interval, it is apparent also that hot and rainy summers show a greater diarrhea and enteritis mortality than hot and dry (or cool) summers. There appears, then, to be some relationship between this disease and both temperature and precipitation. The lag in the relationship to both temperature and precipitation is, however, noteworthy, and may help to explain some of the negative reports on these factors in the literature where an attempt was made to relate deaths and simultaneous climatic conditions.

Further evidence that the climatic factors are indirectly related is obtained from a comparison of rates for cities not widely separated geographically, yet similar from the point of view of altitude and nonresident deaths. Some will consistently run higher than others. Upon investigation the former will often be found to have water supplies comparable with those of the latter but other sanitary provisions, notably sewage and waste disposal, will be found less adequate.

The delayed relationship with climatic factors and the observations just noted give some encouragement for the hypothesis that the housefly—fallen into discredit of recent years as a disease carrier—may actually play something of a role as a vector for some of the diseases included in the broad category of diarrhea and enteritis. Undoubtedly the remainder of the famous complex of food, fingers, and flies plays some role, aided and abetted by improper care of food (inadequate screening and refrigeration), both at the source of supply, in urban distribution centers, and in the home.

Field observations were made upon diarrheal outbreaks on more than one occasion. They appeared throughout the summer primarily in the form of individual household outbreaks, without the close relation between onsets in other attacked households noted in the explosive water-borne gastroenteritis epidemics. Children were attacked more frequently and severely than adults, and the mortality tended to be far higher than with gastoenteritis.

A somewhat puzzling fact about diarrhea and enteritis is that the mortality is considerably higher in male than in female children—a fact commented upon by Bakwin (38), Hosoi and Alvarez (39) and by Ciocco (40).

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In this male preponderance, as in the age and seasonal distribution of cases, there is a close analogy with infantile paralysis. This analogy is even beginning to have regional aspects within the continental United States, at least.

An opportunity for the intensive field study of one diarrhea and enteritis outbreak was presented when the unit was asked to collaborate on the field and laboratory study of an outbreak with a relatively high mortality (117 cases and 12 deaths) in Adair County, Ky. With examinations conducted upon fresh stools, a surprisingly high proportion proved to have bacillary dysentery of the Shiga type. The outbreak was at first confined to homes on the outskirts of Columbia, the county seat, beyond the limits of the town water supply where privies (seldom used by the younger children) and poor sanitary conditions of the homes themselves were noted. Well water supplying these homes was found to be polluted, but there was little relation between the onset of cases in homes using water from the same well, and many homes escaped entirely. A survey of nonattacked homes in this area revealed better screening against flies, more meticulous housekeeping, and better protection of the food between meals. As the epidemic progressed occasional cases were noted in the better type of home, but only 3 cases occurred in homes supplied with running water from the town system. Cases also began to occur on more or less distant farms—often after family visits to or from homes in the stricken area—and outlying foci were set up from which the disease spread to adjacent farms.

Cases occurred at all ages, but children tended to be attacked more often than adults, and the fatal cases were all under 8 years of age. Males were more often attacked than females. The mortality was also greater among males, but the case fatality was the same for both: a point of some interest in connection with the sex differences in mortality noted above.

The outbreak of Shiga dysentery in Adair County started in the latter part of May and lasted throughout the summer—a prolonged affair in comparison with the epidemics described earlier in this section of the report. (See appendix IV.)

While the role of flies in the dissemination of this disease may have been a minor one, it is evidence that the epidemiological picture is hardly that of a water-borne epidemic.

This and other studies made above tend to sustain the view that the role of water as a factor in the mortality complex "diarrhea and enteritis" is a negligible one where present standards of water quality are met and maintained continuously.

Acknowledgments

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APPENDIX I

FORM USED IN FIELD STUDY

WATER-BORNE DISEASE STUDY

Address ______________________________; White ____ Colored ____; Church ______________________

Check person(s) interviewed		Name	Sex	Age	Date first attacked	Hour first attacked	Symptoms: Naus	Vom	Cramp	Diarrh	Other	Place of occupation or school	Visits away from home during period of outbreak	Water used for drinking
	1		M F											
	2		M F											
	3		M F											
	4		M F											
	5		M F											
	6		M F											
	7		M F											
	8		M F											
	9		M F											
	10		M F											

Guests or visitors present during period of outbreak but now left: ____________ Address ____________
Date arrived ____________ Date left ____________

Household water supply: City ____ Well ____ Cistern ____ Spring ____ Other ____
Comments on quality of water during period *preceding* outbreak:
Taste ________ Odor ________ Color ________ Turbidity ________ Other ________

Milk supply: Source ____________ Comments on quality of milk ____________

Food, baked goods, eclairs, door-to-door delivery:

Space for special questions and for extension of remarks above:

Date interviewed ____________ Interviewer ____________ Cooperativeness ____________ (Over)

APPENDIX II

GASTRO-ENTERITIS OUTBREAK IN GEORGETOWN, KY.

Epidemiological Study of Water-Borne Gastroenteritis in Georgetown Ky.

On the 16th, 17th, and 18th of November 1940, a strikingly high prevalence of gastroenteritis in the city of Georgetown, Ky., came to the attention of the Scott County Health Department. Preliminary studies made by that department indicated that the water supply might have been the source of the trouble. The superintendent of the water treatment plant was asked to increase the amount of chlorine in the city water, and this increase was started at noon on the 18th. The State department of health was also notified, and, through the latter's cooperation, the outbreak came to the attention of the water-borne disease study unit of the Ohio River Pollution Survey on the afternoon of Monday, November 18. An intensive study of the outbreak was begun on the morning of Tuesday, November 19.

The study was divided into three broad types of inquiry: (*a*) A house-to-house canvass of a sample of the population to determine the incidence and distribution of the disturbance and its vehicle; (*b*) laboratory studies of the suspected vehicle and of patients to determine, if possible, the primary cause; (*c*) environmental studies of a sanitary character. The present report will deal primarily with the results of the first two of these, the last having been covered in an early separate report owing to the urgency of the need for correcting some of the conditions disclosed.

RESULTS OF THE HOUSE-TO-HOUSE INQUIRY

When questioned as to the character of the illness it was usually described as an acute diarrhea with severe cramps and often accompanied by either nausea, vomiting, or both nausea and vomiting. During the canvass 131 cases were discovered, the detailed symptomatology of which is given in table 1.

Table 1.—*Symptoms described for 131 cases of gastroenteritis, canvassed populations, Georgetown, Ky.*

Sympton	Number of cases
Diarrhea alone	26
Diarrhea and cramps	61
Diarrhea, cramps, nausea, or vomiting	29
Cramps alone	15
Total	131

In general the duration was given as a day or two but a few cases lasted 3 or 4 days. In about 10 percent of the cases it was noted that the initial attack subsided in 1 or 2 days but relapse occurred with quite violent watery diarrhea lasting another 2 or 3 days as though the first attack had paved the way for secondary invaders.

The dates of onset obtained by canvass and by questionnaires addressed to 136 college students are shown in table 2.

TABLE 2.—*Dates of onset of cases of gastro-enteritis in the canvassed population of Georgetown, Ky., and among students of Georgetown College, November 1940*

Group	Dates of onset											
	Prior to Nov. 14	14	15	16	17	18	19	20	21	22	Unknown	Total
College students	6	3	25	31	26	11	6	----	----	----	3	111
Georgetown proper	4	3	5	25	30	29	14	9	2	4	6	131
Total	10	6	30	56	56	40	20	9	2	4	9	242

A limited number of cases occurred in Georgetown College after the 19th—the day on which the questionnaire was submitted. Canvassing continued in the city until the end of the week, by which time it was possible to obtain accurate dates of onset for only a few recent cases.

Cases were not uniformly distributed throughout the city, but tended to be concentrated in the better residential districts and in the college. One section of small dilapidated homes inhabited by colored day laborers escaped entirely, although almost surrounded by a better class of residential homes which were heavily attacked. This poorer section had practically no running water in the home, being supplied almost entirely by small hydrants on the city water supply located near street intersections. Canvassing in this section was quite unsuccessful during daylight hours because few people were at home. The freedom from attack was not wholly racial because colored families uptown where the prevalence was high showed practically the same incidence as the neighboring white families.

The age incidence of the malady was nearly uniform for the various decades of life and is shown in table 3. There is seen to be no concentration of cases in the younger ages so characteristic of milk-borne outbreaks and of the summer diarrheas. Also against the hypothesis that milk served as the vehicle was the fact that the incidence among those taking from all six of the city's principal milk sources, including one distributing adequately pasteurized milk, was very nearly uniform.

TABLE 3.—*Age incidence of gastro-enteritis among the canvassed population of Georgetown, Ky.*

Age (years)	Total canvassed	Total attacked	Percent attacked
Under 2	9	1	11.1
2 to 9	53	10	18.9
10 to 19	101	19	18.8
20 to 29	70	29	41.4
30 to 39	49	13	26.5
40 to 49	57	19	33.3
50 to 59	52	15	28.8
60 to 69	42	19	45.2
70 plus	25	5	20.0
Not specified	6	1	16.7
All ages	464	131	28.2

Food was bought at a diversity of stores by the various households. There was only one door-to-door food vending agency—a bakery wagon from an adjacent city. The largest part of the sales for this wagon consisted of bread and rolls, and many attacked households reported not buying from this agency at all.

The true incidence of the malady in the population of Georgetown was probably considerably above the figure of 28.2 percent shown for all ages in table 3 for reasons which will presently be given. So high an incidence could only be explained on one of two hypotheses; first, that the vehicle was the town water supply, or second, that an exceedingly infectious virus was spread from person to person as influenza is now considered to be spread.

That the first of these seems more likely is suggested by the incidence among those habitually drinking city water compared with the incidence where it was not habitually taken. Nearly all of those using wells or cisterns for their drinking-water supply in Georgetown were interrogated in the house-to-house canvass.

The significance of the difference between the two percentages in table 4 is considerably enhanced by the fact that for 11 of the 12 persons who were attacked, despite the habitual use of other sources of drinking water, it was possible to obtain a history of fairly liberal use of city water while working or visiting outside the home. Had the disease been an air-borne virus there should have been no such marked discrepancy as that shown in table 4 between two groups of Georgetown residents.

TABLE 4.—*Incidence among canvassed persons in Georgetown using city water and among those habitually using private well and cistern water*

Source of drinking water	Canvassed	Attacked	Percent attacked
City water	388	119	30.6
Other sources	76	12	15.8

In addition to including a nearly complete tally of persons using other sources of water supply, table 4 contains a disproportionately large number in the colored section above mentioned where the incidence was found to be very low. The residential section about Georgetown College and the college itself were the sections where the disorder was most prevalent. Questionnaires filled out by students at the college showed 109 or 80 percent attacked. This whole section of the city was covered by canvass much less completely than other areas. For these reasons the incidence for the city as a whole must be regarded as far higher than the figures shown in tables 3 and 4. A reasonable estimate would be a figure not far from 50 percent.

During the course of the canvass a number of statements were obtained about the simultaneous prevalence of the disorder among persons on outlying farms, in adjacent cities, and even in remote centers. These were investigated, so far as time permitted, and usually turned out to be unfounded or based upon the fact that an illness had occurred which was not the same as that experienced by the residents of Georgetown. Occasionally the true version offered a startling confirmation of the water-borne hypothesis. Not a few cases closely resembling those in the city were encountered on outlying farms as sole cases in large households. Upon questioning it was usually found that the patient had visited Georgetown a few days prior to the attack and some of them could recall having ingested nothing but water while in the city. Where the date of visit and date of onset seemed to be remembered accurately these cases were used to establish incubation periods for the disorder. One case had an onset within 12 hours after a 15-minute stopover in Georgetown during which he had taken a glass of water and a ham sandwich. A patient in the Georgetown Hospital was discharged to his farm home on the 17th and developed a typical attack on the 20th. Another patient who visited Georgetown briefly on the 16th was attacked on the 18th. Forty-two students from an Indiana college attended a football game with Georgetown College on the 16th at Georgetown. The day was cold and many, even of the players, denied having taken any water during their 6-hour stay in Georgetown. However, 16 recalled having taken varying amounts of water; only 3 drank freely, the others having had one glass or less. Four cases of gastroenteritis occurred and all 4 occurred among the 16 students with a history of having taken water. All but one had also eaten ice cream or hot dogs. The other recalled having had nothing but water during his stay. The onsets were on the 17th, 18th, 20th, and 21st. The player whose onset occurred on the 17th broke training after the game and may have had other causes for his attack of vomiting and diarrhea.

A number of people were questioned as to whether they had noted any abnormal tastes or odors in the water during the week prior to the outbreak, and several answered that the water was unusually malodorous toward the end of the week. The odor was noted particularly on opening bottles of water kept for some time in the refrigerator. Few could describe the quality of the objectionable smell or taste, but one intelligent response was that it smelled and tasted like rotten wood.

Summing up the results of the house-to-house study, then, the evidence strongly indicates that water was the vehicle by which this infection or intoxication was distributed in Georgetown. That it was more probably an infection than an intoxication is evidenced by the 2- to 3-day incubation period of the few cases having a short enough exposure in the city to justify drawing a conclusion. The agent was probably in the water as recently as Saturday afternoon, November 16.

LABORATORY FINDINGS

During the latter part of the week of November 11 a peculiar blue-black tint was noted in the water of the Royal Spring from which Georgetown receives its water supply. In the settling basins this color was particularly noticeable where the water was not completely obscured by floating masses of decomposing algae. It may be that the latter contributed some of this color, for it was noted that the water in bottles in which some of these algae were collected was tinted quite deep blue after standing. The plant masses were found to be largely composed of a species of *Oscillatoria*. The odor of these samples was very unpleasant, and the taste much like that of rotten wood. Some of this material was autoclaved and ingested with no ill effects. It cannot be said that the algae were entirely incidental to the outbreak, however, for it seems likely that in decomposing they at least added to the organic load of the water. This would help to explain one of the first of the laboratory findings which was that, although the chlorine feed had been markedly increased at noon on Monday, November 18, no residual chlorine was detected in any of the samples taken at noon the following day with but a few hours' detention of treated water at the plant.

Before detailing the bacteriological analyses of the water at the time of the outbreak it may be useful to present the results of the routine analyses of treated city water as shown by the State health department laboratory reports on file in Georgetown for the entire year of 1940. These are detailed in table 5.

TABLE 5.—*Total bacterial counts (37°) and percentage of gas formed in lactose broth at 48 hours in routine analyses of Georgetown water samples for the year 1940*

Date	Total count, per millimeter	Percent gas formed	Date	Total count, per millimeter	Percent gas formed
Jan. 10	5	0	May 21	(3)	(3)
Jan. 17	0	0	July 10	5	0
Jan. 24	9	0	July 16	572	0
Jan. 31	9	80	Aug. 1	5	0
Feb. 7	21	60	Aug. 14	2,163	0
Feb. 9	108	10	Aug. 21	954	0
Feb. 14	3	0	Aug. 28	9,158	0
Feb. 21	1,144	0	Sept. 4	4	0
Feb. 28	954	0	Sept. 11	(4)	(1)
Mar 6	572	0	Sept. 17	2	0
Mar. 10	8	0	Sept. 25	2	0
Mar. 13	508	0	Oct. 2	(2)	0
Mar. 20	8	0	Nov. 8	5	0
Mar. 27	2	0	Nov. 18	28	90
Apr. 3	3	0	Nov. 20	4	0
Apr. 10	5	100	Nov. 25	2	0
Apr. 17	1,144	(1)	Dec. 2	84	0
Apr. 24	0	0	Dec. 4	0	0
May 1	(2)	20	Dec. 16	3	0
May 8	0	0			

[1] No record on gas formed
[2] Over 10,000.
[3] 4 samples from various points showing total counts of 0 or 2 and no gas.
[4] Colored school, 1,271; Garth School, 954.

There is evidently a very substantial variation in the total count and at times extensive gas formation is noted in the presumptive broth tubes after 48 hours, though the degree to which this latter would confirm is not given. Unfortunately, no sample was sent to the laboratory during the week preceding the outbreak (November 10 to 16). The samples were taken at a tap at the water-treatment plant. Some of the variation in total count may be explained on the basis of faulty operation of the filtration plant. However, a decided variation in total count and marked turbidity in the raw spring water is known to occur a few days after heavy rainfall over the collection area feeding the spring. A light, drizzling rain had fallen in Georgetown on Armistice Day, 5 days before the outbreak. There was reason to believe that the rainfall had been heavier south of the town in the region from which the spring receives its water, as the flow was augmented markedly and the water became turbid just prior to the onset of the epidemic. During the 10 days following the rain the temperature fell below the freezing point several times.

The first samples available for bacteriological study after the outbreak began were taken by the county health department at noon on November 18, kept overnight on ice and analyzed the following day. The results of examining these samples—taken at scattered points on the main grid of the distribution system—are shown in table 6a. The results of a second set, taken in all but one instance from similarly scattered but slightly different points on the main grid on the following day, are given in table 6b. The results of a third set, taken chiefly from dead-ends on the same day as those in table 6b (November 19) but studied in a somewhat different manner, are given in table 6c. On the 19th after taking these samples (which showed no residual chlorine despite the increased feeding of chlorine the previous day), the dose was again increased and a residual began to appear in the mains toward evening. Samples taken subsequently showed a heavy residual and were practically sterile.

Except for evidences of high content of gas-forming bacteria, the figures for all but one of the samples of table 6 show a fairly good grade of water; certainly not one which is polluted in the accepted sense of the term. The findings for sample No. 17 are not easily explained except on the basis of contamination at the time of taking the sample.

TABLE 6.—*Results of treated water sample analyses, Georgetown, Ky., Nov. 18 and 19*

Sample station No.	Total count at 37° per cubic milliliter	Most probable number of coliforms per 100 milliliter confirmed	Remarks
A. SAMPLES OF NOV. 18 [1]			
1	[2] 600	Less than 2.2	No gas formation.
2	25	do	48-hour gas formation in 3 of 5 10-cubic centimeter presumptive tubes not confirming.
3	5	do	48-hour gas formation in 1 of 5 10-cubic centimeter presumptive tubes not confirming.
4	25	do	48-hour gas formation in 2 of 5 10-cubic centimeter presumptive tubes not confirming.
5	10	do	48-hour gas formation in 4 of 5 10-cubic centimeter presumptive tubes not confirming.
6	5	do	Do.
7	10	do	48-hour gas formation in all of 5 10-cubic centimeter presumptive tubes not confirming.
B. SAMPLES OF NOV. 19 [1]			
3	10	Less than 2.2	48-hour gas formation in 3 of 5 10-cubic centimeter presumptive tubes not confirming.
8	10	do	No gas formation.
9	[2] 800	do	Do.
10	40	do	48-hour gas formation in 2 of 5 10-cubic centimeter presumptive tubes not confirming.
11	5	do	No gas formation.
12	10	do	Do.
C. SAMPLES OF NOV. 19. (SPECIALLY STUDIED) [3]			
13	160	Less than 1	48-hour gas formation in 7 of 10 10-cubic centimeter presumptive tubes not confirming.
14	20	1	48-hour gas formation in 6 of 10 10-cubic centimeter presumptive tubes not confirming. (1 tube partially confirmed.)
15	10	Less than 1	48-hour gas formation in 1 of 10 10-cubic centimeter presumptive tubes not confirming.
16	25	1	48-hour gas formation in 4 of 10 10-cubic centimeter presumptive tubes not confirming.
17	10	16	48-hour gas formation in 10 of 10 10-cubic centimeter presumptive tubes, 7 confirmed.
18	20	Less than 1	48-hour gas formation in 9 of 10 10-cubic centimeter presumptive tubes not confirming.

[1] Five 10-milliliter lactose broth tubes used for presumptive test. Partial confirmation by 2 percent brilliant green bile broth and MacConkey's agar.
[2] Estimated number.
[3] Ten 10-millilter lactose broth tubes used for presumptive test. Partial confirmation as above.

The remarks on gas formation in these samples should be amplified. In no case did gas appear in the presumptive tubes during the first 24 hours of incubation. In the second and third samples of table 6a it showed in relatively small amounts; in the fourth, fifth, and sixth samples one tube of each set showed explosive gas formation. Fewer samples of table 6b tended to show gas but here again one tube of each set showed explosive development. The general distribution of gas formation among the dead-end samples of table 6c more nearly resembles that for those taken on the main grid the previous day (table 6a), and here also it was explosive in about the same ratio.

Detailed attention has been given to these findings on late gas-formation because they represent a common finding in connection with gastroenteritis outbreaks and suggest the presence of anaerobes which may not be present in large numbers but nevertheless may be etiologically related. Apparently the use of anaerobic culture methods on samples of water suspected of causing gastroenteritis is basically indicated but was, unfortunately not resorted to in the present study.

The samples of table 6c were studied in more detail than can be shown there. Tubes showing no gas were streaked on plates of MacConkey's medium and suspicious colonies fished for further study. In addition two 100-milliliter portions of each sample were filtered by suction through disks of diatomaceous earth in Jenkins filters, the two disks being planted in tubes of lactose broth and Selenite F media, respectively, for enrichment. After 24 to 48 hours the tubes were streaked on MacConkey's plates and suspicious colonies again fished.

By these methods five of the six samples were found to contain bacteria of the genus *Pseudomonas.* One sample contained this organism alone, the other four contained also bacteria of the genus *Alkaligenes.* The one sample from which no cultures could be obtained came from a dead-end at a Civilian Conservation Corps camp nearly a mile out of town where no cases occurred, despite the use of city water.

The study of individual patients gave no further clue to the etiology. The symptomatology has been briefly outlined above. Fever was slight or absent. One blood culture was secured and proved sterile. The blood of 6 patients was studied microscopically: 5 showed white blood cell counts ranging from 5,000 to 7,000 and 1 showed a white count of 12,500. The differential count was uniformly within normal limits.

Six stools freshly passed, were studied microscopically: three showed considerable numbers of a small yellow cell not much larger than a red cell but oval in outline and not dissolving in acetic acid. Presumably these were small yeast cells. The remainder showed no abnormality.

Twenty stools were examined bacteriologically within 3 hours of passage, on the following media: MacConkey's agar, desoxycholate citrate agar, Salmonella-Shigella agar and bismuth-sulphite agar. In addition some of each stool was inoculated into Selenite F enrichment medium and subsequently streaked on MacConkey's agar. Eighteen of the twenty showed a rather sparse growth of the usual coliform colonies. One showed a nearly pure culture of *Pseudomonas* and one showed colonies which gave the cultural reactions of a *Salmonella.* Through the courtesy of Dr. P. R. Edwards of the University of Kentucky, Lexington, this organism was finally identified as *Salmonella panama.* Of the 18 stool specimens showing the usual coliform flora 7 also showed other types of colonies. These, on further study, were found to be coliforms in 5 instances, *Pseudomonas* in 2 and *Proteus* in 2. One stool containing *Proteus* and one containing *Pseudomonas* also had colonies later found to be coliforms.

Only one organisms, *Pseudomonas,* was obtained from both the water and the stool samples and this was found inconstantly in the latter. Despite the inconstancy of its appearance in the stools it seemed advisable to study this organism in some detail. It was formerly regarded as one of the causes of intestinal tract infection; it is known to produce a rather complex toxin fatal to experimental animals when injected subcutaneously. Lacorte, in Brazil, recently described diarrheal death in animals when comparatively small doses of culture filtrates are injected into the duodenum. It is known, also, that the organism can produce cyanide in small amounts of culture There has recently been a recrudescence of interest in this group as one of the causes of diarrheal disease, if not of gastroenteritis.

Studies in our laboratory, which have not as yet been completed, do not, however, support the view that either filtrates of lactose broth cultures or the cultures themselves when taken by human beings orally can produce any symptoms whatever. As many as four billion organisms have been taken of one strain with no

appreciable effect. When large numbers are ingested the organism may appear for a day or so in pure culture in the stool but it is quickly displaced by the normal intestinal flora.

Some importance nevertheless may be attached to *Pseudomonas*. There is evidence that this organism can inhibit or mask the growth of coliforms in mixed cultures, raising the question of whether the absence of gas in presumptive tests where this organism is found definitely excludes the possibility of coliforms also having been present in the sample.

The failure of the laboratory to find a responsible agent in water implicated, for the reasons outlined in the preceding section, was not wholly without precedent. The conditions which cause water-borne gastroenteritis have never been satisfactorily demonstrated. Reasons have been given, however, for considering that the condition has an infectious, probably bacterial, basis.

GENERAL OBSERVATIONS

Back-siphonage and cross connection possibilities were explored by Mr. Perkins of the Kentucky State Health Department. There are no local industries active in Georgetown, the local pasteurizing plant and the college being probably the largest users of water in the city. Certain defective installations were uncovered but it was difficult to see how these could account for so wide-spread an outbreak as the one in question.

It seems more likely that what was probably an infection came through the plant from the original source of supply, the Royal Spring

Reasons have been given, in the report presented shortly after the outbreak, for considering the treatment of water at Georgetown as inadequate, Filtration, and at times chlorination, was shown to be faulty and this is corroborated by the periodic high total counts shown in table 5.

When fires occur, and there were an unusual number of these during the preceding week,[1] the water sometimes receives rather hasty treatment owing to lack of adequate water storage in the distribution system At such times also the flow in the mains is accelerated and sedimented material and bacteria in the mains may be stirred up in considerable numbers.

The possible sources of pollution of the spring were therefore explored at some length.

The Royal Spring is really the outlet of a small underground river flowing through cavernous limestone formation until it reaches the surface at the bottom of a small limestone cliff near the center of Georgetown. There are several such streams in the vicinity of Georgetown, each draining, usually, the higher ground southward from the outlet. Surface water reaches the underground collecting caverns through sinkholes in the bottom of sinks—more or less circular depressions from a few feet to several hundred yards in circumference—scattered along the course of the underground streams.

The practice prevails of dumping all manner of debris in the sinkholes down which surface water drains from these depressions into the underground streams. Such accumulations gradually disappear—even when piled high. There is a small sink nearly filled with ashes located within a hundred feet of the spring. On farms further from the city, sinkholes are convenient burial places for dead animals. The carcasses of the larger animals are, in general, sold to a rendering plant. Sewage also may be piped off to a sinkhole to avoid the necessity of building a cesspool. Many sinkholes are to be found in pastures south of Georgetown where there are extensive accumulations of animal feces.

Under these conditions it is not hard to see why rains over the collecting surface of the spring vastly—and sometimes with incredible rapidity—increase the bacterial load of the water issuing from the Royal Spring. In the underground caverns there are doubtless sludge deposits and the increased current after rains probably stirs these up much as flushing a hydrant roils a water main.

With conditions such as this constant vigilance by trained operators and faultless equipment for treating water are indicated. These are not available in Georgetown.

SUMMARY

An explosive epidemic of gastroenteritis, of short duration, occurred in Georgetown, Ky., on November 16, 17, and 18, 1940, following rains that caused increased flow and turbidity of the water from Royal Spring, the source of the city's water supply.

[1] Four fires occurred on the following dates: Wednesday, November 13, at noon; Saturday, November 16 at 5 a. m. with another at noon; Sunday, November 17 at 9 a. m.

Bacteriological records showed that the effectiveness of water filtration and/or chlorination was quite variable.

The incidence among persons using private well and cistern water for drinking was much lower than in persons using the city supply.

Age and sex distribution of cases in a canvassed population was nearly uniform.

There was a definite incubation period of 36 to 72 hours, suggesting an infectious, rather than a toxic, etiology.

Very few confirmed coliforms were found in samples taken during this investigation. This might be due to increased chlorination beginning when the outbreak became apparent. It is, however, possible some organisms, not ordinarily detected by standard bacteriological methods, may be the cause of attacks of the type of gastroenteritis encountered in this outbreak.

ACKNOWLEDGMENT

Acknowledgement is made of extensive courtesy and assistance on the part of the Kentucky State Health Department, the Scott County Health Department and the officials of the local water plant, also Dr. P. R. Edwards of the University of Kentucky for assistance in determining the identity of certain organisms.

APPENDIX III

GASTROENTERITIS OUTBREAK IN NAVARRE, OHIO

Epidemiological Study of Water-Borne Gastroenteritis in Navarre, Ohio

On the 23d of February 1941 an unusually high prevalence of gastroenteritis in the village of Navarre, Ohio, was brought to the attention of Dr. Underwood, of the Stark County Board of Health. The county health department obtained four water samples from scattered points on the distribution system which, upon bacteriological analysis at the State health department laboratory, revealed the presence of coliforms. Examination for coliforms, presumptive and confirmed, were made on two 10 milliliter and two 1 milliliter portions of each sample. The results of these analyses are shown in table 1.

Table 1.—*Gas formation, confirmed for coliforms, in 4 tap-water samples from Navarre, Ohio, Feb. 24, 1941*

Sampling point	Volume of portion			
	10 milliliters	10 milliliters	1 milliliter	0.1 milliliter
High school	+	−	−	−
"Big Wick's Place"	+	−	−	−
Navarre Club	+	+	+	−
Home of D. A. Fisher	+	+	+	−

On the 25th a routine sample was taken independently at the school and showed no coliforms. On March 1 the State health department, in cooperation with the Stark County Health Department, made a careful study of the local situation and took duplicate samples from (1) water at the pumping station before the pumps were started, (2) the same after the pumps had been in operation for a considerable period, (3) the Sohio gas station, (4) the Herwick saloon, (5) Reamer's filling station, and (6) the high school. Each duplicate sample was examined independently, making 12 samples for this one day. Those from the high school both showed gas confirming for coliforms in one of the two 10 milliliter portions, none in the 1 milliliter portions. The remaining samples were negative for coliforms.

An emergency hypochlorinator was obtained and installed and on March 8 duplicate samples from three points on the distribution system were all negative.

Through the cooperation of the State and county health departments the gastroenteritis study unit of the Ohio River Pollution Survey was permitted to make an extended study of the outbreak, beginning on the 7th of March. A house-to-house canvass of a considerable portion of the village population was first made and then a series of field laboratory and sanitary engineering tests were conducted.

RESULTS OF HOUSE-TO-HOUSE CANVASS

The village of Navarre had 1,703 inhabitants at the time of the 1940 census. The canvass included 382 persons in 106 households distributed throughout the village. A total of 115 cases occurred in the canvassed population The incidence of 30 percent obtained from these figures is low for reasons which will be stated below.

Data on the time of occurrence of cases are somewhat obscure. The canvass was begun on March 7 and the outbreak had occurred fully 2 weeks before that time, so that dates of onset were not readily obtained, though a calendar was

carried by the canvassers to assist the informants when there was doubt. Table 2 gives, however, the best available picture of the distribution of cases in respect to time.

TABLE 2.—*Dates of onset of cases in the canvassed population*

Cases	Dates of onset, February							
	Prior to Feb. 22	22, Sat.	23, Sun.	24, Mon.	25, Tues.	26, Wed.	27, Thurs.	28, Fri.
Cases with onset on given date	7	20	26	13	8	4	3	2

There were some definite irregularities about the distribution of cases within the village. The northern, eastern, and central portions suffered heavily but the western and southern portions had few cases.

The age incidence shows no striking differences in the various decades. The figures for the canvassed population are given in table 3. The disorder tended to prevail in the middle decades of life and was considerably less in the younger and older decades.

TABLE 3.—*Age incidence of gastroenteritis in the canvassed population of Navarre, Ohio*

Age	Attacked	Total canvassed	Percent attacked	Age	Attacked	Total canvassed	Percent attacked
Under 2	2	11	18	50 to 59	12	45	27
2 to 9	14	55	25	60 and over	8	49	16
10 to 19	21	61	34	Unknown	2	2	
20 to 29	21	55	38				
30 to 39	20	50	40	All ages	115	382	30
40 to 49	15	54	28				

This age incidence is quite characteristic of both person-to-person contact outbreaks and of water-borne outbreaks. Against the contact hypothesis is the explosiveness and short duration of the outbreak as shown in table 2. Influenza itself could hardly have reached a peak and declined so rapidly as this outbreak did. More definite, however, than the foregoing indication is the difference between the incidence among persons drinking water from private well supplies and those drinking water supplied by the city; 51 persons were found using private wells, of whom only 7, or 13 percent, were attacked. On inquiry it was found that every one of these seven had habitually used village water while at school or at work. All of the individuals sure of having taken no water from the public supply escaped. Most of these persons had had the same contact opportunities as others living in the village.

Of the 331 canvassed individuals using the village supply habitually, 108 were attacked—an incidence of 33 percent. Had the canvass been made closer to the time of the outbreak more cases might have been recalled. It was noted that inquiries made in the later days of our investigation showed fewer cases than those made in the earlier days, even in the same parts of the village, suggesting that mild cases had been forgotten. It is probably safe to put the figure for the village as a whole at not far from 40 percent.

The relative immunity of the western and southern sides of the village is not difficult to explain. These are areas of relatively low water use and of correspondingly little flow of water through the mains, the principal flow being rather from the pumping station and storage tank in the northwest to the dairy and bakery toward the center of town and the southeast.

No other common factor could be found. Food was bought at various stores. Baked goods were supplied as often by the local bakery as by a delivery wagon selling goods made in a distant city. The incidence was about equal among families on several milk routes.

As in other places where these outbreaks have occurred, many statements were collected during the canvass to the effect that a number of other more or less distant localities had been simultaneously affected, and that persons on private well supplies both in the village and on outlying farms had been attacked. These

reports were carefully investigated. In one instance, what appears to have been a typical attack (but was possibly a case of food poisoning) was found on a farm near the village limits where the use of village water was denied. In other instances, isolated cases were found on the surrounding farms; invariably among children attending the village school. The fact that these cases did not spread to others in the household is further evidence against the hypothesis of spread by person-to-person contact.

These outlying cases are of some epidemiological importance in addition to the assistance they offer in determining the vehicle for the outbreak, for it will often be found that they supply sufficient data for establishing an incubation period. The schedule used in canvassing provides a space for recording visits away from home at the time of the outbreak and visitors to households in Navarre from out of town during the same period. Only two such visitors to a canvassed household in Navarre could be traced; they were a wife and her husband who had come to Navarre from Cuyahoga Falls to visit the wife's family. The two had remained only an hour; neither eating any food and only the wife drinking water. Two days later the wife was attacked with nausea, cramps, and diarrhea. The incubation period of 36 to 72 hours has been noted in other outbreaks and offers a strong clue to the fact that a true infection and not a mysterious poison underlies the syndrome of water-borne gastroenteritis. It was possible to learn of only two attacked persons who left town during the outbreak. Both were school teachers who left Friday evening and were sick immediately on their return Monday morning. The probability is that they had been infected on Friday because the incubation period would otherwise be too short. Their evidence would place the infectious element in the water as late as Friday the 21st.

LABORATORY AND SANITARY DATA

The laboratory evidence indicating that pollution of the water supply had occurred has been presented in the introduction. It remained to determine whether this pollution had occurred at the source of supply or at some point along the distribution system. As the outbreak seemed too widespread to have resulted from a back siphonage or defective cross-connection, attention at first centered on the source of supply.

A detailed report of the sanitary study of the wells and pumping station of Navarre made by Mr. Lathrop on March 1, 1941, is on file in the sanitary engineering division of the Ohio State Health Department. Here is suffices to note that 5 wells in the northwest part of the village, from 30 to 40 feet deep and with casings about 20 years old, constituted the water supply. They form a line parallel with an old canal (now a relatively stagnant lagoon) and about 40 feet from it. The remains of the canal towpath lie between the canal and the wells. On the other side of the line of wells and from 50 to 100 feet away flows the Tuscarawas River in a sharp curve. When the wells were first installed they must have been further from the river than at present, but now the current has undercut the bank so that it comes within 50 feet of one of the wells. When the river is in flood the wellheads are submerged; only a 2-foot rise above the level observed at the time of the survey would have accomplished this. There had been, however, no such flooding of the wellheads for months before the present outbreak.

When uncapped, these wells flow a few inches over the casing, indicating a head of water greater than the river and perhaps greater than that of the nearby canal. Continuous pumping, however, draws the level down 10 or 12 feet.

The pumping station on the line of wells contains an electrically driven pump which sends the water to the main on Wooster Street and into the village grid. An elevated storage tank provides pressure when the pumps are not working and is located on the north edge of the town at the head of Park Street.

Only one of the wells (No. 5) could be tested individually because the valves at the wellheads were considered rusty and unreliable. This well, however, was the one nearest to a badly polluted section of the lagoon and also nearest to the river. Tests were accordingly first made on this one well on March 21. The bacteriological tests consisted of a standard water analysis for coliforms, with detailed attention to the type of growth in the lactose broth tubes. Two supplementary chemical tests were also made for chlorides and for hydrogen ion concentration. The characteristics of the two potential sources of pollution—the river and the lagoon—with respect to the various tests may be briefly outlined.

The sewage from the city of Massillon and various industrial plant wastes are carried by the river, which therefore was high in coliforms and chlorides but relatively low in pH (7.1). The lagoon showed few coliforms (about 20 per 100 milliliters), the chlorides 8.5 parts per million and the pH was 7.7. Any coliforms in the wells could come from either source and, as the normal well water customarily ran lower in chlorides than the river or the lagoon, the chlorides should rise with prolonged pumping if pollution were drawn in from either source. The hydrogen ion concentration of the wells might, however, assist in differentiating. The normal well water ran a pH of 7.3 to 7.4, and a tendency for this to drop or rise under prolonged pumping would indicate pollution from the river or the lagoon, respectively.

The results of the tests on well No. 5 are given in table 4 under date of March 20. The continued absence not only of coliforms but of any growth whatever in the fermentation tubes, the tendency for the chlorides to drop, and the relative constancy of the pH gave a fairly definite proof of the lack of pollution of the well from either source during the hour-and-a-half test run. Eleven and a half inches of vacuum were carried during this period which was considered excessive for prolonged pumping. This well was, therefore, cut out for the night and allowed to refill. Pumping on it was resumed in the morning for another hour and a half. Two samples were secured from this run—an early and a final one. The results of tests on the second run confirmed the first; they are given in table 4 under date of March 21.

TABLE 4.—*Test of well No. 5, Navarre, Ohio, Mar. 20 and 21, 1941*

Date	Time	Total count per milliliter	Coliforms per 100 milliliter	Chlorides parts per million	Hydrogen ion concentration
Mar. 20	3:30 p. m.	3	0	4.7	7.4
	3:50 p. m.	2	0	4.0	7.4
	4:10 p. m.	1	0	4.0	7.4
	4:25 p. m.	0	0	3.5	7.4
	5:15 p. m.	1	0	3.7	7.4
Mar. 21	9:45 a. m.	0	0	5	7.2
	11:36 a. m.	0	0		
	10:40 a. m.	0	0	4.7	7.3

As the remaining wells could not be tested individually, it was decided to make a prolonged pumping test on all the wells and to waste through hydrants at dead ends in order to prevent excessive pressures in the system. An order was issued to boil all drinking water in the village on the morning of the test, a pressure-recording gage was installed in a home near the uppermost part of the system, and the elevated tank filled and cut off to provide water for use in case of fire. The emergency chlorinator was then shut off and the pumps were started at 10 a. m. Hydrants were successively opened until six were flowing at one time. It was found possible to maintain fair pressure in the system under these conditions, but the vacuum at the wells reached 12 inches—the maximum it was felt the wells could take, and at 1:30 p. m. the pumping and wasting were discontinued.

During this period regular samples were taken at the wells for bacteriological and chemical tests as on the test of well No. 5. Samples were also secured of the turbid water shortly after dead-end hydrants were opened and also just before they were closed. A pronounced hydrogen sulfide odor was noted in the water at the pump house and at several of the dead ends toward the close of the test period.

Table 5 shows the results of the various tests at the wells. Table 6 shows the findings for the samples from the dead ends, both initially and at the end of the run.

TABLE 5.—*Bacteriological and chemical findings during test of wells, Navarre, Ohio, Mar. 25, 1941*

Sample No.	Time	Most probable number of coliforms per 100 milliliters	Most probable number of bacteria per 100 milliliters	Slow lactose fermenters	Pseudomonas	Chlorides, parts per million	Hydrogen ion concentrates
1	10:05 a. m.	0	2.2	0	0	7.5	7.3
2	10:35 a. m.	0	0	0	0	4.0	7.3
3	10:50 a. m.	0	0	0	0	4.0	7.3
4	11:19 a. m.	0	0	0	0	4.2	7.3
5	11:50 a. m.	0	5	0	0	4.0	7.3
6	12:20 p. m.	0	9	0	+	4.0	7.3
[1] 7	12:50 p. m.	0	12	0	+	4.0	7.3
[1] 8	1:20 p. m.	0	39	0	+	4.0	7.3

[1] Strong odor of hydrogen sulfide in these last samples.

The most striking fact about table 5 is that an increasing number of bacteria begin to appear after prolonged pumping as shown in the column headed "Most probable number per 100 milliliters" from 11:50 a. m. to 1:20 p. m. These bacteria were of two kinds only: One, a *Pseudomonas*, producing a characteristic water-soluble green pigment on certain media and the other an organism as yet unidentified. The latter appears to be only a saprophyte, but the former may conceivably have pathogenic significance. Organisms of the genus *Pseudomonas* have long been suspected of causing enteric disturbances. However, several detailed studies have been made on them in this laboratory, whole cultures being ingested by volunteers without evident ill effects. Their appearance in water may, however, be of significance from other points of view. It is known that they are very widely distributed in nature and that they are common in sewage. They are more filterable than coliforms and conceivably might be an early index to pollution. Organisms of this genus are known to produce cyanides under certain conditions of growth. Finally, their presence may interfere with the detection of coliform organisms.

These facts would seem to warrant making an effort to rid the supply of these organisms even though their direct pathogenicity cannot be proven. Because they occur, even after prolonged pumping, in small numbers, it is probable that they originate from one well only. This well may also be the source of the hydrogen sulfide odor noted as being particularly strong at the very end of pumping. Because of the difficulty of determining which well is involved, it may be necessary to rely solely upon chlorination of the supply as the most practical way of dealing with these organisms. In this connection, however, it should be noted that the occurrence of hydrogen sulfide is an unfavorable factor where chlorine is used, tending to limit considerably its effectiveness, unless proper allowance is made for absorption of chlorine by the sulfide.

So much for the findings of the study of the source of supply. The results of the study of the distribution system are presented in table 6. The total count per cubic centimeter is seen to have been abnormally high only in the Ohio Street loop, suggesting some degree of stagnation. Frequent flushing of this loop would seem to be indicated. The index type of coliforms was not encountered in the test at any time. The bacterial most probable number was high due to the extensive stirring up of the system. Late lactose fermenters and *Pseudomonas* were isolated from all but a few of the samples.

TABLE 6.—*Bacteriological findings on samples from dead ends and hydrants, Navarre, Ohio*

Sampling point	Total count per milliliter		Most probable number coliforms per 100 milliliters		Most probable number bacteria per 100 milliliters		Slow lactose fermenters		Pseudomonas	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed	Open	Closed
North and Main Sts	2	0	0	0	[1] 110	21	+	+	+	0
North Market and corporate line	1	0	0	0	[1] 110	9	+	+	0	+
4th and Columbiana Sts	1	0	0	0	[1] 110	39	0	0	0	+
Columbiana and Canal	2	0	0	0	[1] 110	39	+	+	0	+
Tuscarawas and 4th Sts	0	1	0	0	[1] 110	39	+	+	+	0
Tuscarawas and 2d Sts	1	0	0	0	[1] 110	39	0	+	+	+
Ohio and Main Sts	50	0	0	0	[1] 110	39	+	+	+	0
Ohio and Wilmott Sts	59	1	0	0	[1] 110	15	+	0	+	+
Wooster and east corporate line	0	0	0	0	2.2	39	0	+	0	+
Canal and Main Sts	1	0	0	0	48	39	+	+	+	0

[1] Over.

While no evidence was found of pollution from points inside the water distribution system on this rather drastic test, there are grounds for believing that such pollution actually may have taken place. The coliforms found in the early samples examined by the State health department apparently could not have come from the wells, and if they did not they must have come from some point inside the system. The peculiar distribution of cases in the village offers some rather uncertain clues as to the point of entrance. Cases were most numerous (nearly 100 percent) on the line from the elevated storage tank at the head of Park Street down to Wooster Street and along Wooster Street toward the center of town. The west end of Wooster Street is supplied by the main carrying water from the pumping station to the elevated storage tank and few, if any, bona fide cases occurred on this main. The inference is that pollution occurred at some point on Park Street north of Wooster and that polluted water either filled the tank, whence it was carried throughout the village, or that it was fed into the main close to the base of the tank and so was distributed to the town. With the exception of a plugged sewer connection for a house nearly at the top of the hill on Park Street, no remotely conceivable source for pollution was found at the time these studies were made. However, the distribution of cases makes this a distinct possibility.

The maintenance of a fair chlorine residual in the water at all times would tend to minimize the danger of recurrence if this hypothesis is correct and would also serve to help to remedy the situation noted under the discussion of the bacteria found in the water at the wells. The advisability of safeguarding this supply by continuous and effective chlorination cannot be too strongly recommended.

Periodic sampling of the water at various points throughout the distribution system, including two or three samples from homes near the tank, is also recommended, on the chance that a mild recurrence may be detected.

A pressure recording gage located either at the pumphouse or at the top of the hill near the storage tank would provide invaluable information about conditions within the system and about the frequency and duration of pump runs. Lack of such data greatly complicates the understanding and prevention of outbreaks like the present one.

Grateful acknowledgment is made of the active cooperation in this study rendered by the Stark County Board of Health and by officers of the State department of health.

APPENDIX IV

DYSENTERY OUTBREAK (SHIGA) IN ADAIR COUNTY, KY.

Laboratory Findings in an Outbreak of Shiga Dysentery

On June 26, 1941, the Kentucky State Health Department requested the services of the mobile laboratory of the epidemiological unit of the Ohio River Pollution Survey for the study of an epidemic of diarrhea with an unusually high mortality in Columbia, Adair County, Ky. The general epidemiological findings of this outbreak are to be described by Caudill and others elsewhere; the present note will outline some of the advantages of having a well-equipped mobile laboratory for use in epidemiological control of diarrheal disease outbreaks in areas remote from centers with laboratory facilities and will give certain basic laboratory findings in detail.

The mobile laboratory used in the study here described was housed in an 18-foot trailer towed by a coupe. Electricity for lights, hot plate, incubator, oven, and serological bath was provided through an electric cable with sharp-pointed spring clamps for attachment to any electric service wires carrying sufficient amperage and voltage. Water was obtained by a hundred-foot hose attachable to any faucet. Tanked gas was carried for the autoclave and for Bunsen burners. When the trailer was located, the tow car could be unhitched and driven independently for the purpose of distributing specimen containers and bringing specimens back to the laboratory.

This unit was based at Cincinnati, Ohio, some 200 miles north of Columbia. On the day that the request for the laboratory was received a stock of MacConkey's and of Krumwiede's triple sugar agar was made up and other media of possible value in the isolation of organisms of the Eberthella, Shigella, and Salmonella groups from stools were stocked on the trailer in dehydrated form.

The laboratory left Cincinnait at 7:30 a. m. on June 27, arrived in Columbia at 3:30 p. m., and was located and set up, ready for operation, by 4 p. m. of the same day.

The choice of media was not a hard one to make when a few cases had been reviewed hastily. Patients were of all ages and appeared to be toxic, stools were passed frequently and consisted of limited amounts of tenacious pus and mucus, or of blood-streaked creamy pus and mucus. MacConkey's agar and Shigella-Salmonella agar (Difco) plates were poured and prepared for streaking. All plates were cooled under wet towels in a stream of air from an electric fan.

Meantime, stool-specimen outfits were left with a number of patients. Each outfit consisted of paper plates, paper spoons, and sterile metal containers without preservative. The patients were instructed to defecate on the plate and transfer the specimen to the container by means of the spoon. Plates were left in the homes upside-down on a table and covering the spoons so that flies could not contaminate them. Where freshly removed diapers were available, these were taken to the laboratory direct, without using the containers.

By 8 p. m.—4 hours after the trailer was installed—the plates had dehydrated sufficiently for use and 18 stool specimens had been secured. These were inoculated in duplicate, both on MacConkey's and on Shigella-Salmonella agar, and were incubated at 37° C. By noon of the following day a fair growth of colonies, suspicious in appearance, was present on many of the plates. Presumptive agglutinations were made directly from the colonies on the plates with 1/20 dilutions of the following diagnostic rabbit antisera: Shiga, polyvalent dysentery, and Flexner. The majority of the colonies selected gave good agglutination with the first two, but none with the last antiserum. Suspicious colonies were also fished to Krumwiede's triple sugar agar slants and positives subsequently were purified and carried through the various cultural and serological reactions necessary for identification.

One of the outstanding advantages of the use of mobile laboratories in the control of epidemics like the one described here is that quck and efficient laboratory diagnosis is supplied. Although further stools were examined upon which more comprehensive data will be presented below, it may be of interest to outline briefly the final results of the analysis of the first 18 stool specimens to illustrate this point.

When carried through triple sugar, sugar fermentation, and serological reactions, 12 of the 18 stool specimens were found to be positive for Shiga dysentery. The 18 specimens had been secured from 14 patients (some patients having supplied more than 1 stool) and the number of patients represented by the 12 positive specimens was 8. The 6 negative sets of plates were from the stools of 5 patients, all of whom were in the second or third week of their illness; 1 set of plates was overgrown and could not be studied further.

Having completed the first, or diagnostic phase of the work, the mobile laboratory was brought back to Cincinnati on June 30, for administrative reasons. On July 21, the trailer was returned to Columbia where it remained until August 8. In the interval the epidemic in Columbia proper had begun to subside, but small rural foci of dysentery had developed, some of which were small unrelated outbreaks, perhaps of Flexner and paradysentery, others of which were clearly related to the urban focus of Shiga. The aid of the Red Cross had been invoked and a small hospital for dysentery patients had been set up. Also, the question of the advisability of a convalescent carrier study had been raised. The second visit of the mobile laboratory had, therefore, not only a case diagnostic, but also a carrier, study function to perform.

As the laboratory was not present throughout the period of the epidemic, it will be evident that the cases diagnosed definitely by stool analysis represented only a limited number of the total cases which occurred during the whole period of the outbreak, including no cases for the period of June 30 to July 21, inclusive. Some attempt was made to bridge this gap by securing blood samples for agglutination from persons who recovered, were in the third or fourth weeks from the onset of their illness, and who had not been otherwise studied during the acute phases of the attack. Because the carrier study was added to the diagnostic study during the second visit the total number of positive isolations became only a limited fraction of the total number of stool examinations made.

Before presenting the results of the analyses it may be useful to detail the procedure adopted in order to convey some idea of the scope of the work which it is possible to carry out in a well-equipped mobile laboratory. During the second visit of the trailer an assortment of sugar media was stocked to permit cultural study and complete equipment for serological study was also included. The following routine was then adopted: When a stool specimen was brought in it was streaked on duplicate plates of MacConkey's and Shigella-Salmonella agar and in several instances a microscopic examination of the stool was made, the presence or absence of mucus, pus, or blood cells being noted.[1] After 18 to 24 hours incubation at 37° C. the stool specimen plates were examined and suspicious colonies were fished to Krumwiede's triple sugar agar slants. After 24 hours' incubation at 37° C. the Krumwiede's slants were read and those with typical Eberthella-Shigella reactions [2] were subjected to presumptive agglutination and were purified. Purified cultures were transferred to nutrient agar slants to develop growth for antigen for final serological confirmation and were inoculated into mannitol, glucose, sucrose, lactose, maltose, rhamnose, and tryptone broths (the latter for indole testing). In the fourth 24-hour period the first readings were made on the reactions in the sugar media and final agglutination tests were made. Dilutions of Shiga, polyvalent dysentery, and Flexner rabbit antisera up to $\frac{1}{3600}$ were prepared for this purpose. Thus by the fifth day a definite conclusion as to the nature of the organism was obtained.

A total of 211 stool specimens were collected from 94 patients. Forty-six of the specimens from 27 patients were found to be positive for dysentery and dysenterylike organisms. A great many of these cases were examined because of the occurrence of diarrhea, even though there was no history of contact with, or proximity to, cases or foci of known Shiga dysentery. There were 132 stools from patients whose relationship, familial or geographic, with known Shiga patients led to a strong suspicion that they were Shiga cases. Of these 31 were

[1] These microscopic checks were found to be unexpectedly useful because on certain days stools of many convalescents at the hospital were noted grossly to be flecked with red, causing some consternation among the attendants. Microscopically, no blood cells could be seen, and the red flecks were identified as fragments of stewed tomatoes served on the previous day.

[2] Acid butt, without gas, and no change in slant.

positive for Shiga dysentery. The 132 specimens were supplied by 49 patients and the 31 positive specimens represented a total of 17 diagnosed cases of Shiga dysentery. The remaining positive cultures, which were from cases of dysentery, Shiga (2 cases), Sonne (4 cases), Hiss (2 cases), Flexner (1 case), and typhoid fever, E. typhosa (1 case), will be discussed when the cultural and serological characteristics of the organisms are presented.

The low ratio of positive specimens to total examinations was due in part to the fact that a large number of examinations for carriers was made. A better measure of total effectiveness in diagnosis will be given below when the results of the analysis of stools of this group are presented according to the duration of the disease.

As nearly all stool examinations were made in duplicate on MacConkey's agar and on Shigella-Salmonella agar it may be useful to compare the results obtained by the use of the two.

TABLE 1.—*Comparison of MacConkey's agar and Shigella-Salmonella agar for the isolation of organisms of the Shigella group from stools*

	Number of stool specimens
Findings on duplicate plates of MacConkey's and Shigella-Salmonella agar:	
Both plates positive	25
Both plates negative	155
MacConkey's positive, Shigella-Salmonella negative	3
MacConkey's negative, Shigella-Salmonella positive	21
Comparison not possible	7
Total	211

These results are shown in table 1 where, of 204 examinations in which a comparison is possible, MacConkey's agar gave positives in 28 examinations, and Shigella-Salmonella agar in a considerably higher number—46. Because of the large number of negative examinations made necessary by the carrier study the total percentages of success with either medium are low; a fairer basis might well be the total proportion of each which was positive with either medium or both. By this measure it will be seen that Shigella-Salmonella agar gave 46 out of the total 49 positive, while MacConkey's agar gave only 28.

In actual practice, the advantage from the use of Shigella-Salmonella agar in trailer laboratories is considerably greater than would appear from abstract figures for the following reasons:

1. It is more readily available for use than MacConkey's because it does not have to be autoclaved before use.

2. Plates may be directly streaked with fairly heavy inocula without dilution or other precautions against overgrowth and only one plate need be used for each stool.

3. The number of suspicious colonies tends to be greater and coliform colonies fewer, giving a far better selection.

The extent to which positive stool findings could be made with either medium singly at varying intervals after the onset of diarrhea is shown in table 2. Here, as in previous discussions of results, the data are given for all findings and then for cases presumed to have been Shiga dysentery on the basis of contact with previous cases or foci of infection.

TABLE 2.—*Number of stools examined at specified intervals after onset of the disease, and number and percent positive on MacConkey's and on Shigella-Salmonella agars*

Interval in days (inclusive)	Total number of stools examined	Positive MacConkey	Positive Shigella-Salmonella agar	Percent positive MacConkey	Percent positive Shigella-Salmonella agar
	(A) All specimens				
0-3	[1] 37	10	17	28	46
4-7	35	12	19	34	54
8-15	[1] 51	5	10	10	20
16-60	[1] 70	0	0	------	------
	193	27	46	14	24
	(B) Specimens from Shiga contacts				
0-3	[1] 22	8	12	38	57
4-7	18	7	8	39	44
8-15	[1] 31	4	6	13	19
16-60	[1] 64	0	0	0	0
	135	19	26	14	19

One stool in each of these intervals is not examined on MacConkey's agar.

The percentages for positives on Shigella-Salmonella agar in table 2, it will be noted, are but little higher than those for MacConkey's, but they tend to be consistently higher in the three groups where positives were obtained. Table 2 also shows that by the end of the second week very few stools were found to be positive and that a sizeable group of examinations for the third and succeeding weeks (16 to 60 days) gave no positives at all. These 70 examinations, however, represent stool studies on only 27 patients. If the carrier rate for Shiga dysentery is actually in the neighborhood of 3 percent [3] it could easily happen that this number of patients might have been examined without finding one positive. The results of the somewhat limited number of microscopical examinations are briefly presented. A great many of the stools received from patients early in the disease showed mucus, pus, and blood upon gross examination. The same findings, of course, were evident on microscopical examination with significant exceptions heretofore mentioned. Where mucus, pus, and blood were in evidence, the stool was commonly found to be positive on bacteriological examination. The comparative findings are shown in table 3.

TABLE 3.—*Microscopical and bacteriological findings in stools of 35 patients where microscopical examination was done*

Microscopical findings	Total with specified microscopical findings	Positive bacteriologically for dysentery
Negative for mucus, pus, and blood	17	[1] 2
Mucus and pus only	4	2
Mucus, pus, and blood	14	12
Total	[2] 35	18

[1] One of these, a fatal case in an infant, was negative on microscopical and positive for Shiga dysentery The other was a paradysentery case.
[2] 8 stools showed parasitic ova, as follows: Ascaris, 4; enterobius, 3; dog tapeworm, 1.

The cultural, biochemical, and serological characteristics obtained on the organisms isolated are presented in tables 4 and 5. On the basis of the consensus of the characteristics determined the first 19 cultures in order in these tables are judged to be Shiga strains, the next 4 are considered Sonne types; the next 2, Hiss Y; and the last 2, Flexner and *E. typhosa*, respectively.

[3] Kolmer, J. A., and Taft, L., Clinical Immunology, Biotherapy, and Chemotherapy, 1st ed., p. 568 W. B. Saunders & Co., 1941.

TABLE 4.—*Cultural characteristics of organisms isolated*

Culture No.	Krumwiede triple sugar slants		Motile	Indole	Action on carbohydrates				Alcohols	
	Slant	Butt			Glucose	Lactose	Sucrose	Maltose	Mannitol	Rhamnose
1	NC	A	–	–	A	–	–	–	–	–
2	NC	A	–	–	A	–	–	–	–	–
4	NC	A	–	–	A	–	–	–	–	–
6	NC	A	–	–	A	–	–	–	–	–
9	NC	A	–	–	A	–	–	–	–	–
10	NC	A	–	–	A	–	–	–	–	–
11	NC	A	–	–	A	–	–	–	–	–
13	NC	A	–	–	A	–	–	–	–	–
14	NC	A	–	–	A	–	–	–	–	–
15	NC	A	–	–	A	–	–	–	–	–
19	NC	A	–	–	A	–	–	–	–	–
20	NC	A	–	–	A	–	–	–	–	–
22	NC	A	–	Trace	A	–	–	–	–	–
23	NC	A	–	–	A	–	–	–	–	–
25	NC	A	–	–	A	–	–	–	–	–
26	NC	A	–	–	A	–	–	–	–	–
27	NC	A	–	–	A	–	–	–	–	–
29	NC	A	–	–	A	–	–	–	–	–
12	NC	A	–	Trace	A	–	–	A	A	A
16	NC	A	–	–	A	–	–	A	A	A
17	NC	A	–	–	A	–	–	–	A	A
28	NC	A	–	–	A	–	–	–	A	A
7	NC	A	–	Trace	A	–	–	–	A	–
18	NC	A	–	Trace	A	–	–	A	A	–
3	NC	A	–	+	A	–	A	–	A	–
24	NC	A	+	–	A	–	–	A	A	–

TABLE 5.—*Serological characteristics of organisms isolated—Agglutination of Antigens by following rabbit antisera*

Antigen No.	Antidysenteric sera					Eberthella typhosa
	Polyvalent	Shiga	Flexner	Sonne	Hiss	
1		1,280				
2		1,280				
4	1,280	1,280	–	–	40	
6		1,280				
9		1,280				
10		1,280				
11		1,280				
13		1,280				
14		1,280				
15		1,280				
19	1,280	1,280	–	–	–	
20		1,280				
22		1,280				
23		1,280				
25		1,280				
26		1,280				
27		1,280				
29		1,280				
12	–	–	–	640	–	
16	–	–	–	640	–	
17	–	–	–	640	–	
28	40	–	–	1,280	–	
7	640	–	160	–	1,280	
18	320	–	–	–	320	
3	640	–	640	–	320	
24	80	–	–	–	160	5,120

Note the dilutions given indicate the highest titre in which at least a 3 plus or better agglutination was obtained. All antigens were made up to a standard density and the full titre of the respective antisera for their homologous antigens was: Shiga, 1–1,280; Flexner, 1–640; Sonne, 1–1,280; Hiss, 1–1,280; *E. typhosa*, 1–5,000.

Certain deviations in the characteristics found for the organisms thus listed, from the usual descriptions given in the literature, should be noted. While indole production was not shown by any of the cultures when the test was made by the Ehrlich-Böhme procedure, faint traces (more definite with 7 and 18) of indole

were produced by cultures 7, 12, 18, and 22, when tested by the more sensitive method of Gore. According to available descriptions indole is not produced by the Shiga, Sonne, and Ambigua members of the dysentery group, nor by *E. typhosa*, but is produced by the Hiss, Flexner, Strong, and Dispar dysentery strains. With the exception of culture 22, which shows a trace of indole produced, all of the cultures considered to be Shiga types, present a very clear-cut picture.

In the instance of the four cultures listed as Sonne types, the serological results definitely support this decision but all four cultures failed to ferment lactose or sucrose with acid production and two of them, 17 and 28, likewise, failed to ferment maltose. Similarly, cultures 7 and 18 are definitely Hiss strains serologically, but strain 18 ferments maltose with acid production.

In general, however, it is thought that the classifications made here are correct and that the clear-cut serological evidence outweighs the minor discrepancies noted in the sugar fermentations. This is supported by the knowledge that the established criteria for this group are not exact. It is only in the case of culture 3, tentatively identified as a Flexner type, that some doubt exists. Its failure to ferment maltose and its agglutination to a fair titre, 1–320, with Hiss antisera suggests a close relationship to the Hiss strain. However, this culture 3 ferments sucrose and the typical Hiss strain does not.

In passing it might be noted that the polyvalent antiserum used by us was remarkably lacking in Sonne antibodies.

An attempt was made to get blood samples for agglutination tests from individuals who were in the third or fourth week from the onset of their dysenteric infection. For various reasons it was found to be difficult to obtain these specimens. Moreover, the quantity of blood secured in each instance was usually small. As a result only 24 specimens of patients' sera were available for study and the volume of each serum was such that they could be tested against not more than four antigens. A representative Shiga strain from the current study (Adair Shiga) and stock dysentery cultures of Shiga, Flexner and Sonne types were selected for use as antigens. Three of the blood specimens obtained, Nos. 2, 13, and 23, were from patients whose stools had been cultured and from which typical Shiga cultures had been isolated. (See cultures Nos. 2, 13, and 23 in tables 4 and 5). The remaining blood specimens were from individuals who had suffered from dysentery during the current epidemic but no bacteriological examinations had been made of their stools. The results obtained from the study of these patients' sera are presented in table 6.

TABLE 6.—*Results of agglutination tests with patients' sera* [1] *set up against antigens of known species and of a representative Adair County Shiga strain*

Patient serum No.	Titre [2] of patients' sera against antigens for—			
	Stock Shiga	Adair Shiga	Stock y-Flexner	Stock Sonne
2	160	320	320	—
13	—	—	160	—
23	20	20	—	—
30	80	80	320	—
31	80	80	40	—
32	—	—	40	0
33	—	20	—	—
34	—	—	—	—
35	—	—	40	—
36	—	—	—	—
37	—	—	320	—
38	—	—	320	—
39	160	320	160	—
40	40	80	320	—
41	20	20	640	—
42	—	—	320	—
43	—	—	—	—
44	—	—	160	—
45	—	—	80	—
46	—	—	20	—
47	—	—	—	—
48	—	1, 280	320	—
49	640	20	—	—
50	—	—	—	—

[1] Patients' sera Nos. 2, 13, and 23 were from cases yielding cultures of the same numbers as shown in tables 4 and 5. All other sera are from uncultured cases.

[2] Titres recorded here represent a 2-plus or better agglutination as set forth on p. 235 of Diagnostic Procedures and Reagents, 1st ed. ,1941, American Public Health Association.

In determining significant titres for agglutination tests consideration must be given to the strength of the antisera used and to agglutinability of the antigens subjected to their action. In obtaining the results of table 5 fairly potent antisera were used and it is thought that agglutinations below a dilution of 1–320 of the antisera should not be considered significant. With patients' sera, such as those used in obtaining the results shown in table 6, much lower titres are to be anticipated. Considered from the standpoint of the antigens used the Shiga strain is distinctive serologically while the other members of the dysentery group, particularly the Flexner types, tend toward group, and to some extent auto, agglutination. Consequently, it is believed that with patients' sera titres of 1–40 or over against Shiga strains should be considered significant and with the other varieties of dysentery bacteria titres of at least 1–80 and possibly 1–160, should be required.

With these titres as a criterion, it is noted from table 6 that six patients' sera, Nos. 2, 30, 31, 39, 40, and 49, gave agglutinations to significant titres of 1–40 or higher with the antigen of the stock Shiga culture and six sera, Nos. 2, 30, 31, 39, 40, and 48 yielded significant titres of 1–40 or over with the Adair County Shiga antigen. The failure of serum 48 to agglutinate the stock Shiga antigen while it agglutinated the Adair strain in high titre, and the agglutination by serum 49 of the stock Shiga antigen in high titre while it failed to affect the Adair Shiga antigen above a titre of 1–20 is most unusual. These tests with sera 48 and 49 were repeated twice with identical results. A remarkable specificity in the case of these two sera is indicated. Similarly, the unusually high titres for patients' sera, 1–640 and 1–1,280, suggest a marked antibody production for a specific organism. Thus the agglutination of Shiga antigens in significant titres of 1–40 or over by 7 of 24 patients' sera studied is definite evidence, and confirms the observation, that a considerable portion of the dysentery cases in this epidemic were Shiga infections.

No agglutinations of Sonne antigen were observed with any of the 24 patients' sera, even in the 1–20 dilution, although this antigen agglutinated to the full titre of the diagnostic Sonne antiserum used as a control.

Twelve of the 24 patients' sera, namely Nos. 2, 13, 30, 37, 38, 39, 40, 41, 42, 44, 45 and 48, agglutinated Flexner antigen to significant titres. As the bacteriological findings obtained in this study disclosed only one possible Flexner strain this would definitely suggest a very high incidence of endemic Flexner dysentry in this locality with a Shiga infestation superimposed in the present epidemic.

SUMMARY

Using the facilities of a well-equipped trailer laboratory a bacteriological study was made of a dysentery epidemic. The marked value of such a mobile laboratory for use at the site of an epidemic is demonstrated.

In this study 211 stools from active cases of dysentery and from convalescents (some as removed as 60 days from onset of infection) were examined.

From these 211 stools representing 94 patients bacteriological diagnosis was made of 27 cases; 19 Shiga, 4 Sonne, 2 Hiss, 1 Flexner, and 1 typhoid fever.

A brief characterization of the organisms isolated is presented.

A serological study of 24 patients' sera indicates that the current epidemic was a Shiga infection and that dysentery of the Flexner type is endemic in this territory.

ACKNOWLEDGMENTS

It is desired to express our indebtedness to various officials of the Kentucky State Department of Health for their cooperation and assistance; also to the various departments of the city of Columbia, particularly the Water Department; and especially to Dr. J. T. Duncan, county health officer of Adair County, for his cordial and effective cooperation during the time we were making this investigation; and to the medical and nursing staff of the temporary Red Cross hospital that was established at Columbia during the outbreak.

APPENDIX V

OUTBREAKS OF GASTROENTERITIS TRACED TO WATER SUPPLIES

Locality	First cases noted				Duration of epidemic (days)	First water samples taken			Coliforms in early samples	Source of water supply	Population		Percent attacked	Remarks
	Day of—			Day of month		Month	Day	Days from start			Exposed	Attacked		
	Year	Week	Month											
SOURCE OF, AND BACTERIOLOGICAL EVIDENCE FOR, POLLUTION NOT FOUND														
Georgetown, Ky	1940	Friday	Nov	15	5	Nov	18	3	0	Spring	4,500	2,250	50	Unusual number of fires; turbid spring.
Cohasset, Mass	1931	Sunday	Mar	15	4	Mar	19	3	0	Wells	3,000	1,000	33	Active flushing of hydrants just before.
Coshocton, Ohio	1936	Tuesday	Feb	18	(1)	Feb	20	2	0	Well	11,000	1,500	17	Freezing and thawing, flooding.
Milwaukee, Wis	1938	Monday	Feb	7	21+	Daily		0	0	Lake	600,000		11	Sewage blown toward water intake.
SOURCE OF, OR BACTERIOLOGICAL EVIDENCE FOR, POLLUTION FOUND														
"Indiana town"	1940	Thursday	Feb	1	(1)				(?)	River	7,700		26	New filters installed; turbid water in mains.
Navarre, Ohio	1941	Saturday	Feb	22	3	Feb	24	2	+	Wells	1,700	680	40	Active flushing of hydrants just before.
Springfield, Mo	1936		July	16–17	(1)	July	13–23	0	+	Impounded, spring, well.	65,000	20,000–35,000		Source not described.
"Tennessee town"	1936	Week ends	June–Aug	(2)	Brief				(?)	Spring	2,500	765	31	Leak from sewer above spring.
Dallas, Tex	1937		Apr	8	6	(1)	(1)		+	Wells	10,000	3,000	30	Source not found.
Altamount, N. Y	1937	Monday	May	17	13	(1)	(1)		+	Surface	900	190	20	Do.
Vinton, Iowa	1938	Wednesday	Feb	2	6–7	Feb	7	5	+	Wells	3,400	2,000	59	Possible pollution of wells.
OUTBREAKS WITH SEWAGE POLLUTION FOUND AND FOLLOWED BY TYPHOID FEVER CASES														
Excursion steamer	1912		July	29	2–3				(1)	River	1,200	600	50	Water pumped while steamer over sewer.
Santa Ana, Calif	1924		Jan	1	(1)				+		27,000	10,000	37	Plugged sewer flooding water.
Detroit, Mich	1926		Feb	25	(1)	Daily		0	+	River	1,300,000	45,000		Sewage blown toward water intake.
Greater Rostow, Russia.	1926		Apr		14–21	Apr	24	(?)	+	do	260,000	40,000	15	Leak from sewer above spring.
Chicago Stock Yard fire.	1934		May	19					(1)	Lake	(?)	300		Cross connection with polluted supply.
Rochester, N. Y	1940	Thursday	Dec	12	4	Dec	12	0	+	River	280,000	40,000	9	Do.

[1] Not stated. [2] Recurrent.

APPENDIX VI

DIARRHEA AND ENTERITIS MORTALITY STATISTICS AND RELATED DATA FOR 144 CITIES IN THE OHIO RIVER BASIN

City and State	Population 1935 (estimated)	Diarrhea and enteritis death rates per 100,000, 1933–37		Altitude, feet above sea level	Latitude, north	Region	Source of water supply
		Mean	Corrected for residence				
Decatur, Ala	15,983	52.5	48.3	568	34.7	South	Surface.
Florence, Ala	12,329	60.2	57.2	496	34.7	do	Do.
Huntsville, Ala	12,366	59.9	56.3	628	34.8	do	Ground.
Cairo, Ill	12,696	27.2	23.1	311	37.0	Northwest	Surface.
Champaign, Ill	22,588	8.3	8.5	738	40.1	do	Ground.
Danville, Ill	38,259	21.7	16.1	601	40.1	do	Surface.
Harrisburg, Ill	11,531	52.0	58.8	368	37.7	do	Do.
Mattoon, Ill	15,170	18.4	17.7	739	39.5	do	Mixed.
Urbana, Ill	14,471	17.8	15.1	725	40.1	do	Ground.
Anderson, Ind	44,826	19.2	18.4	873	40.0	do	Mixed.
Bedford, Ind	13,862	30.5	29.6	697	38.9	do	Surface.
Bloomington, Ind	21,554	19.7	20.7	748	39.1	do	Mixed.
Connersville, Ind	12,842	18.7	19.3	836	39.6	do	Ground.
Crawfordville, Ind	10,466	18.6	16.9	757	40.0	do	Do.
Elwood, Ind	11,130	46.3	46.3	860	40.2	do	Do.
Evansville, Ind	110,744	22.1	20.3	374	37.9	do	Surface.
Frankfort, Ind	12,500	17.1	16.9	854	40.2	do	Ground.
Huntington, Ind	13,130	22.0	22.9	742	40.8	do	Do.
Indianapolis, Ind	389,148	19.9	18.7	765	39.7	do	Mixed.
Jeffersonville, Ind	12,874	39.3	43.2	448	38.2	do	Ground.
Kokomo, Ind	34,234	22.2	22.4	814	40.4	do	Do.
Lafayette, Ind	28,119	23.9	17.9	600	40.4	do	Do.
Logansport, Ind	16,945	8.2	7.5	606	40.7	do	Surface.
Marion, Ind	24,875	25.7	25.2	813	40.5	do	Ground.
Muncie, Ind	51,562	25.4	23.6	942	40.1	do	Mixed.
New Albany, Ind	27,236	21.1	31.9	413	38.3	do	Surface.
Newcastle, Ind	13,811	21.1	36.3	1,031	39.9	do	Ground.
Peru, Ind	12,890	7.9	11.8	642	40.7	do	Do.
Shelbyville, Ind	10,667	16.9	24.3	768	39.5	do	Do.
Terre Haute, Ind	61,172	20.7	30.4	485	39.4	do	Surface.
Vincennes, Ind	17,768	41.5	62.3	427	38.6	do	Do.
Ashland, Ky	36,249	54.6	50.2	511	38.4	South	Do.
Bowling Green, Ky	13,448	62.6	65.1	499	37.0	do	Do.
Covington, Ky	69,318	23.8	21.7	513	39.0	do	Do.
Fort Thomas, Ky	9,958	0	-------	852	39.1	do	Do.
Frankfort, Ky	11,547	32.9	33.9	560	38.2	do	Do.
Henderson, Ky	11,417	66.3	64.3	374	37.8	do	Do.
Hopkinsville, Ky	11,266	69.2	76.8	556	36.9	do	Do.
Lexington, Ky	47,838	43.2	39.7	967	38.0	do	Do.
Louisville, Ky	344,174	20.7	19.9	459	38.2	do	Do.
Middlesborough, Ky	10,896	110.0	91.3	1,066	36.6	do	Do.
Newport, Ky	29,961	6.6	9.9	506	39.1	do	Do.
Owensboro, Ky	25,436	49.6	48.1	403	37.7	do	Ground.
Paducah, Ky	37,947	55.6	54.5	344	37.0	do	Surface.
Jamestown, N. Y	48,278	8.6	6.9	1,322	42.0	Northeast	Ground.
Olean, N. Y	22,434	16.6	13.8	1,435	42.0	do	Surface.
Asheville, N. C	61,042	29.2	24.2	2,115	35.5	South	Do.
Alliance, Ohio	23,771	9.5	9.0	1,079	40.9	Northeast	Mixed.
Ashland, Ohio	11,894	6.8	6.3	1,077	40.9	do	Surface.
Barberton, Ohio	26,497	10.1	10.1	965	41.0	do	Do.
Bellaire, Ohio	12,458	13.2	12.1	677	39.9	do	Do.
Bucyrus, Ohio	9,829	14.1	12.1	1,004	40.7	do	Do.
Cambridge, Ohio	17,644	14.1	11.7	801	40.0	do	Do.
Campbell, Ohio	16,394	7.0	12.0	772	41.0	do	Do.
Canton, Ohio	113,816	6.0	5.5	1,050	40.7	do	Ground.
Chillicothe, Ohio	19,599	10.5	10.3	632	39.3	do	Do.
Cincinnati, Ohio	476,118	21.3	19.4	554	39.1	Northwest	Surface.
Columbus, Ohio	317,332	15.6	13.7	766	39.9	Northeast	Do.
Coshocton, Ohio	10,939	17.8	16.6	770	40.2	do	Ground.
Dayton, Ohio	225,199	14.5	13.5	764	39.7	Northwest	Do.

DIARRHEA AND ENTERITIS MORTALITY STATISTICS AND RELATED DATA FOR 144 CITIES IN THE OHIO RIVER BASIN—Continued

City and State	Population 1935 (estimated)	Diarrhea and enteritis death rates per 100,000, 1933–37		Altitude, feet above sea level	Latitude, north	Region	Source of water supply
		Mean	Corrected for residence				
East Liverpool, Ohio	24,292	13.8	12.0	686	40.5	Northeast	Surface.
Hamilton, Ohio	57,427	23.4	20.1	598	39.3	Northwest	Ground.
Ironton, Ohio	17,930	48.1	43.3	515	38.5	Northeast	Surface.
Lancaster, Ohio	20,721	18.0	15.7	898	39.7	do	Ground.
Mansfield, Ohio	36,376	8.5	7.7	1,152	40.7	do	Do.
Marietta, Ohio	13,865	19.4	16.3	624	39.4	do	Surface.
Marion, Ohio	32,682	16.2	15.4	908	40.5	do	Ground.
Martins Ferry, Ohio	15,969	26.3	18.9	654	40.0	do	Do.
Massillon, Ohio	30,877	8.3	7.6	986	40.7	do	Do.
Middletown, Ohio	33,190	41.8	37.2	664	39.5	Northwest	Do.
Newark, Ohio	32,539	14.9	13.7	822	40.0	Northeast	Surface.
New Philadelphia, Ohio	13,192	6.5	8.0	889	40.4	do	Ground.
Niles, Ohio	17,933	11.1	17.1	887	41.1	do	Do.
Norwood, Ohio	37,636	1.8	2.8	624	39.1	Northwest	Mixed.
Piqua, Ohio	16,494	12.5	11.4	882	40.1	do	Surface.
Portsmouth, Ohio	47,339	65.1	53.4	497	38.7	Northeast	Do.
Salem, Ohio	10,784	10.3	7.0	1,207	40.8	do	Ground.
Springfield, Ohio	72,692	9.7	9.4	983	39.9	Northwest	Surface.
Steubenville, Ohio	38,881	18.6	14.7	711	40.3	Northeast	Do.
Struthers, Ohio	11,521	10.5	15.3	834	41.1	do	Do.
Warren, Ohio	48,069	6.7	5.2	889	41.2	do	Do.
Wooster, Ohio	11,140	12.5	12.0	910	40.8	do	Ground.
Xenia, Ohio	10,713	22.4	24.0	917	39.7	Northwest	Do.
Youngstown, Ohio	188,726	9.8	8.8	851	41.0	Northeast	Surface.
Zanesville, Ohio	39,876	19.5	16.2	699	39.9	do	Ground.
Aliquippa, Pa	32,961	10.3	16.0	751	40.6	do	Do.
Ambridge, Pa	23,979	8.1	12.6	750	40.5	do	Do.
Arnold, Pa	10,738	7.4	10.0	786	40.6	do	Surface.
Beaver Falls, Pa	19,322	11.7	10.9	766	40.7	do	Do.
Bellevue, Pa	10,347	9.7	8.3	727	40.5	do	Ground.
Braddock, Pa	18,554	13.8	11.0	782	40.3	do	Surface.
Bradford, Pa	21,197	11.9	11.1	1,437	41.9	do	Mixed.
Butler, Pa	23,463	8.3	9.9	1,011	40.8	do	Surface.
Cannonsburg, Pa	13,524	4.8	4.1	933	40.2	do	Do.
Carnegie, Pa	12,988	8.0	11.4	769	40.4	do	Do.
Charleroi, Pa	10,982	0	------------	764	40.1	do	Do.
Clairton, Pa	15,817	10.2	14.9	1,020	40.3	do	Surface.
Connellsville, Pa	13,031	19.4	15.9	882	40.0	do	Do.
Coraopolis, Pa	10,922	7.3	12.0	720	40.5	do	Ground.
Donora, Pa	13,789	2.9	4.5	900	40.1	do	Surface.
Dormont, Pa	13,018	1.5	2.1	750	40.3	do	Do.
DuBois, Pa	10,549	13.5	10.9	1,399	41.1	do	Do.
Duquesne, Pa	22,591	8.6	13.3	850	40.4	do	Ground.
Ellwood City, Pa	12,317	13.0	12.0	894	40.9	do	Surface.
Farrell, Pa	13,742	8.7	13.5	940	41.1	do	Do.
Franklin, Pa	10,075	8.0	9.4	1,000	41.4	do	Mixed.
Greensburg, Pa	17,248	16.8	12.1	1,100	40.4	do	Surface.
Homestead, Pa	19,985	12.3	12.9	756	40.3	do	Do.
Jeannette, Pa	17,375	3.8	5.1	1,000	40.3	do	Do.
Johnstown, Pa	66,824	12.0	9.6	1,176	40.3	do	Do.
Latrobe, Pa	10,866	14.7	11.3	1,008	40.3	do	Do.
McKeesport, Pa	58,558	16.3	13.2	752	40.3	do	Do.
McKees Rocks, Pa	18,819	3.4	6.3	725	40.4	do	Ground.
Meadville, Pa	17,763	12.7	10.3	1,078	41.6	do	Do.
Monessen, Pa	21,317	10.9	13.6	762	40.1	do	Surface.
Munhall, Pa	13,364	6.0	7.5	754	40.4	do	Do.
New Castle, Pa	50,545	10.4	9.5	806	41.0	do	Do.
New Kensington, Pa	19,152	14.9	12.7	775	40.5	do	Do.
North Braddock, Pa	17,711	4.9	6.6	1,000	40.4	do	Do.
Oil City, Pa	22,476	7.5	6.6	1,027	41.4	do	Ground.
Pittsburgh, Pa	702,556	8.3	7.2	726	40.4	do	Surface.
Sharon, Pa	25,614	12.5	10.3	854	41.2	do	Do.
Swissvale, Pa	18,590	5.0	7.6	922	40.4	do	Do.
Turtle Creek, Pa	10,295	3.9	6.7	750	40.4	do	Do.
Uniontown, Pa	21,471	29.8	20.6	1,017	39.9	do	Do.
Vandergrift, Pa	11,089	10.8	15.4	800	40.6	do	Mixed.
Warren, Pa	15,159	12.1	10.4	1,168	41.8	do	Do.
Washington, Pa	26,080	26.8	21.7	1,039	40.1	do	Surface.
Wilkinsburg, Pa	32,260	4.1	3.7	922	40.4	do	Do.
Bristol, Tenn	13,004	26.1	28.4	1,689	36.6	South	Do.
Chattanooga, Tenn	150,751	35.7	32.1	660	35.0	do	Do.
Johnson City, Tenn	30,935	25.4	16.0	1,631	36.2	do	Ground.
Kingsport, Tenn	13,156	21.1	16.5	1,270	36.6	do	Surface.

DIARRHEA AND ENTERITIS MORTALITY STATISTICS AND RELATED DATA FOR 144 CITIES IN THE OHIO RIVER BASIN—Continued

City and State	Population 1935 (estimated)	Diarrhea and enteritis death rates per 100,000, 1933–37		Altitude, feet above sea level	Latitude, north	Region	Source of water supply
		Mean	Corrected for residence				
Knoxville, Tenn	119,796	37.8	32.9	905	35.9	South	Surface.
Nashville, Tenn	171,630	36.7	33.0	498	36.1	do	Do.
Bluefield, W. Va	21,371	64.8	40.8	2,560	37.2	do	Ground.
Charleston, W. Va	70,808	84.1	58.9	600	38.3	do	Surface.
Clarksburg, W. Va	29,368	17.6	14.3	1,034	39.2	do	Do.
Fairmont, W. Va	25,817	31.2	25.3	886	39.4	do	Do.
Huntington, W. Va	88,272	36.6	30.4	565	38.4	do	Do.
Morgantown, W. Va	18,220	27.6	28.4	892	39.7	do	Mixed.
Moundsville, W. Va	16,283	7.0	8.9	630	37.4	do	Ground.
Parkersburg, W. Va	34,411	38.8	30.7	601	39.2	do	Do.
Wheeling, W. Va	64,385	15.7	12.9	637	40.0	do	Surface.

SUPPLEMENT F

BIOLOGICAL STUDIES

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BIOLOGICAL STUDIES

Summary

The primary purpose of the biological studies in connection with the Ohio River Pollution Survey has been twofold: First, to determine present biological conditions as a record to be compared with conditions after future changes due particularly to remedial measures which may be instituted, and second, to determine the effect, particularly of a destructive nature, of present sources of pollution on stream biological communities and fish life as a guide in judging the need for corrective measures.

Secondary purposes include determination of what biological and chemical conditions may be typical of different pollutional situations, what factors under man's control are involved in creating these situations, and what combinations of these conditions may be allowed for designated stream uses.

This biological supplement is based upon extensive data obtained from the examination of plankton and fish collections and correlated with chemical and bacteriological findings. Fish collections were made only during the second year of study and did not include the middle third of the basin nor the main Ohio River.

Biological life is closely related to problems of stream sanitation. A change in the magnitude or the nature of the pollution load will almost without exception cause a change in the lower biological forms and, as these are food for fish life, fish, in turn, are also affected. An increase in the minute forms or plankton may affect water supply due to taste and odor troubles or filter clogging difficulties caused by certain types when present in large numbers.

While pollution is usually considered to damage or destroy aquatic life and recreational values and this is frequently the case, it is possible for moderate pollution to provide food material and increase aquatic life, particularly in an otherwise naturally barren stream. This might be termed a beneficial effect as far as fish life is concerned and may parallel a detrimental effect if the increase in plankton causes taste, odor, and filter clogging difficulties in water supply systems.

Corrective measures in the nature of sewage treatment remove a portion of the organic pollution load and stabilize a further portion. Thus the destructive effect of pollution on aquatic life may be corrected and, at the same time, a large measure of the food material retained. An over-all benefit to aquatic life may thus be accomplished by a treated effluent. Pollution has only a damaging effect on water supply, and treatment measures reduce this effect to a greater or lesser degree but never entirely eliminate all effects.

Pollutants which enter streams from city sewers or organic industrial plants, such as canneries, meat-packing houses, and creameries, affect the aquatic life in a variety of ways. The waste may have an immediate toxic effect on aquatic life or, more usually, the waste

may induce rapid multiplication of aerobic bacteria which sharply lower the dissolved oxygen concentration, sometimes to the asphyxial level for fishes, or even to total depletion.

The lowering of the dissolved oxygen concentration to a point below 3 parts per million, accompanied by a high oxygen demand and high coliform bacterial population, is evident in a zone of heavy organic pollution, below sources of pollution, the distance depending upon the temperature, rate of flow, and physical character of the stream. Biologically, this region is dominated by bacteria-eating protozoa, colorless flagellates and chlorophyll-bearing flagellates that require a rich cultural medium. The fish are principally of the coarser varieties, such as carp and buffalo.

This zone gradually blends through an intermediate stage into a fertile zone which is characterized by a large variety and volume of photosynthetic plankton organisms and dissolved oxygen above 5 parts per million. In this region is usually found a large mixed plankton population, reflecting the maximum fertilizing effect of the upstream pollution. Fish are varied and abundant, there being large numbers of market and food fishes.

Further downstream the plankton volume is diminished. This reduction in fish food has a direct effect upon the fish population, so that the game fishes are the dominant forms.

Industrial wastes such as effluents of coal mines, steel mills, paper and pulp mills, oil and gas refineries, in sufficient concentration, reduce the aquatic life, either by a direct toxic action or by a reduction in hydrogen ion concentration (pH 4.5 or less). The flesh of fish in streams polluted by oil refineries or paper mills is tainted and cannot be used as food.

The condition of a stream from a biological standpoint will vary with conditions. During spring high water, for example, zones of heavy pollution and intermediate zones are scarce. As the year advances and low-flow conditions set in, the polluted areas are more distinct and it is the summer low-water period that is critical to the fish population of a stream. A period which exterminates a fish population may be only 1 day of the year and it is not offset by the tolerable conditions of the other 364 days.

In general, localities where normal biological communities and fish life were found to be detrimentally affected or destroyed and pollutional forms found to predominate, corresponded to localities where information on sources of pollution and chemical and bacteriological data indicated that large sources of pollution exist. Outstanding examples are the upper Ohio River and tributary areas, where acid pollution, chiefly from mines, has destroyed all but the very specialized aquatic forms capable of existing in acid water, and below the larger cities and in some instances larger industries that continue to discharge wastes without treatment. Conditions below individual sources of pollution and in other areas throughout the basin are discussed in the drainage basin summaries.

Introductory and General

AUTHORIZATION

This biological survey was conducted as part of the Ohio River pollution survey, authorized in section 5 of the River and Harbor Act passed August 26, 1937. This section reads in part as follows:

The Secretary of War is hereby authorized and directed to cause a survey to be made of the Ohio River and its tributaries to ascertain what pollutive substances are being deposited directly or indirectly therein, and the sources and extent of such deposits, and with a view to determining the most feasible method of correcting and eliminating the pollution of these streams.

Activities in connection with the Ohio River survey have divided themselves into three broad groups: (1) The collection of data on water supply, sewerage, sewage disposal, and industrial wastes, together with the location, character, and amounts of polluting wastes; (2) laboratory studies (biological, chemical, and bacteriological) relative to the sanitary conditions of the streams at the time of sampling; (3) hydrometric studies on the stream discharge, time of flow, and the possible dilution at the time of sampling.

When the survey was originally planned, the watershed was to be divided into three parts and a year was to be spent on each third. The middle third, from Point Pleasant, W. Va., including the Big Kanawha Basin, to Carrollton, Ky., including the Kentucky River Basin, was studied in 1939. However, due to subsequent shortening of the time allowed for the survey, both the upper and lower thirds of the watershed were studied in 1940.

In order that this supplement may be complete in itself, certain data on stream flow, drainage basin characteristics, population, bacteriological data, and chemical data, presented in the main body of the Ohio River pollution survey report, have been repeated.

The Scioto River has been studied as a separate project (U. S. Public Health Bulletin No. 276) and is discussed briefly in appendix I to this supplement. The Tennessee River is being studied by the Tennessee Valley Authority, and that organization has submitted a brief progress report on the studies, which is presented as appendix II to this supplement.

PERSONNEL AND ACKNOWLEDGMENTS

The laboratory operations of the survey were performed under the administrative direction of Sanitary Engineer Director J. K. Hoskins, in charge of the Stream Pollution Investigations Station at Cincinnati, who was succeeded in July 1940 by Medical Director H. E. Hasseltine. The work was organized and carried out under the technical direction of Sanitary Engineer Director H. W. Streeter, with Associate Biologist F. J. Brinley in immediate charge of the biological studies. Junior Aquatic Biologist L. I. Katzin assisted Dr. Brinley during the second year of the work.

Special Expert W. C. Purdy and Senior Biologist J. B. Lackey, from the regular staff of the Cincinnati station, cooperated in acting as technical advisers in various phases of the work. Dr. Lackey also prepared appendix I to this supplement, covering biological studies on the Scioto River, based on his studies covered in Public Health Bulletin No. 276.

Numerous fish specimens were submitted to the Laboratory of Interior Fisheries Investigations, United States Bureau of Fisheries, under the direction of Dr. M. M. Ellis.

Grateful acknowledgment is made to Dr. E. L. Bishop, director of health of the Tennessee Valley Authority, for the Discussion of the Biology and Pollution of the Tennessee River, which is included as appendix II of this supplement. The appendix is a joint report of the

Forestry Relations and the Health and Safety Departments and was prepared by Dr. A. H. Wiebe, chief, and Dr. C. M. Tarzwell, associate aquatic biologist, Biological Readjustment Division, Forestry Relations Department, and Mr. G. R. Scott, senior sanitary engineer, and Dr. A. D. Hess, assistant aquatic biologist, Health and Safety Department.

PHYSICAL CHARACTERISTICS OF THE OHIO BASIN

The Ohio River, which is formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pa., drains an area of 204,000 square miles in the eastern central United States (fig. 1), including parts of the following 14 States: New York, Pennsylvania, Maryland, Virginia, North Carolina, Ohio, Indiana, Illinois, West Virginia, Kentucky, Tennessee, Georgia, Alabama, and Mississippi. The tributaries studied in the biological survey consisted of the Allegheny, Monongahela, Muskingum, Hocking, Little Kanawha, Kanawha, Big Sandy, Little Sandy, Guyandot, Miami, Little Miami, Licking, Kentucky, Green, Wabash, and Cumberland Rivers.

Limestone and shale are the common bedrocks found in the Ohio Basin. The northern section of the watershed is overlaid with glacial drift, forming the deep and fertile soils in the western section of the basin. In the Appalachian highlands, in the eastern part of the basin, the soil is light and sandy, while in the south central basin it is alluvial, consisting of a mixture of rich loam and clay. The important natural deposits are coal, iron, oil, and gas. Portions of the Appalachian coal fields extend along the eastern section of the basin from western New York southwest to Alabama. The so-called eastern interior fields lie in parts of southwest Indiana, Illinois, and western Kentucky. Oil and gas have been developed in the Appalachian fields of New York, Pennsylvania, Ohio, West Virginia, and Kentucky, the Lima-Indiana fields in southwest Ohio and eastern and southern Indiana, and in the Illinois fields in central and southern parts of the State.

Three major physical divisions characterize the Ohio Basin. Rough hills and mountains of the Appalachian highlands prevail in the east. Low hills, of the interior plateaus, occupy the southwest. Gently sloping, glacial lowlands of the interior plains are found in the north and northwest.

Navigation on the entire length of the Ohio River, during all times of the year, has been made possible by the construction of 46 locks and dams providing a 9-foot low water channel. Locks and dams also have been built on the Allegheny, Monongahela, Muskingum, Kanawha, Kentucky, Green, and Cumberland Rivers.

INTRODUCTION

There are two principal factors which influence all biological survival: (1) Self-preservation, which includes securing and assimilation of food, and escaping enemies, and (2) race preservation, which includes reproduction in addition to the functions of self-preservation.

Food, therefore, becomes a very important and often the limiting factor in the life of an individual, race, or of a biological community. One aspect of the food relation of a community is expressed as the food chain or chemical cycle of the ecologist. Plants synthesize complex organic compounds from soluble salts and carbon dioxide, either

Fig. I


OHIO BASIN
FIG. I
LAKE ERIE
N. Y.
PENNA.
MD.
OHIO
W. VA.
VIRGINIA
KENTUCKY
INDIANA
ILLINOIS
TENNESSEE
N. CAR.
S. CAR.
GEORGIA
ALA.
MISS.
MO.
PITTSBURGH
CLEVELAND
TOLEDO
COLUMBUS
CINCINNATI
LOUISVILLE
EVANSVILLE
INDIANAPOLIS
CHICAGO
ST. LOUIS
BALTIMORE
WASHINGTON
RICHMOND
NASHVILLE
KNOXVILLE
CHATTANOOGA
MEMPHIS
YOUNGSTOWN
CANTON
AKRON
DAYTON
FORT WAYNE
SOUTH BEND
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
MARCH 1941

by means of solar energy through the agency of a pigment such as chlorophyll, or by means of other energy-yielding chemical reactions. These plants and their products may form food for various animals who, in turn, may be eaten by larger animals. Eventually, carbon dioxide is returned to the air, and soluble materials to the soil and water through the agency of the natural chemical processes carried on by the higher organisms, or through the destructive action of bacteria, molds, and fungi upon organic material no longer living. Thus, the cycle is completed.

The other important aspect of the community food relation lies in competition for the same (usually) limited food supply between organisms not in the relation of prey and predator. In the process of organic evolution the competition for survival has led to such diversifications that there is usually a single species, or restricted group of species, best fitted to survive and reproduce under a given set of environmental conditions. Conversely, it is usual that a certain set of conditions must obtain before a given species can hold its own in competition with others.

The above considerations hold for the aquatic environment as well as for the terrestrial and aerial. The microscopic aquatic plants and plantlike animals synthesize organic materials from the chemical constituents of their fluid surroundings, under the influence of sunlight, giving off oxygen as a byproduct. These minute organisms may form the food of larger Protozoa, of Mollusca, Rotifera, small Crustacea, and larval or even adult fishes. Such plankton-feeders may in turn form the food of larger fishes, and so on. Eventually, compounds of carbon no longer living (wastes, dead organisms) are returned to the water, and broken down through progressive steps, by the bacteria, until nothing but soluble inorganic salts are left, and the cycle commences again. The amount and kind of aquatic life depends ultimately upon the concentration and availability of food in the stream. Thus, a stream may be considered as a nutritive medium for the life growing therein.

Many factors may temporarily interrupt or modify the chain of events, as by removing certain links such as the fish, or by adding organic material in bulk. The most significant factors are man's activities. For the moment attention will be focused on the material he places in the water, hereafter termed "pollutants."

For practical reasons, it is necessary to limit the discussion of this matter to the two ends of the food chain—the microscopic forms that turn material in solution into their own organic substance, and the fishes. The intermediate forms are all important, but are eventually dependent upon these lowest forms. The fish, in turn, are the members of the aquatic community that come most directly to the attention of man, and are most usually his immediate concern.

A small stream which has just received a heavy load of domestic sewage can be taken as an example. This sewage is compounded of human excrement, waste food, paper, etc. It is immediately attacked by the bacteria of the stream. Such a point of gross pollution is characterized by large numbers of coliform bacteria (from excrement), a high rate of oxygen consumption, due to organic material being oxidized, a low dissolved oxygen value due to the use of the oxygen by the rapidly multiplying bacteria, and usually a low population of phytoplankton (plant plankton forms). This deficiency of plankton

may be due to general toxicity of the sewage, particularly if industrial wastes are involved, and of the initial byproducts of bacterial decomposition, and to the lack of available food materials in solution.

Several species of bacteria-eating Protozoa, such as *Paramecium*, *Stentor*, *Colpoda*, *Glaucoma*, *Colpidium*, *Vorticella*, and *Carchesium*, may occur in significant numbers in grossly polluted areas, more abundantly in the slime and scum on stones and sticks and on the surface of the bottom mud than in the plankton. Fish, with the possible exceptions of buffalo and carp, are absent under these conditions. As the sewage moves downstream, the complex organic compounds are reduced by bacterial and chemical means to simpler chemical compounds. Certain microscopic plants, such as *Euglena*, *Lepocinclis*, and *Phacus*, which thrive in a medium rich in organic material, may make their appearance in large numbers. As chemical breakdown continues, these plants will give way to *Pandorina*, *Eudorina*, *Trachelomonas*, *Scenedesmus*, *Chlamydomonas*, and *Mallomonas*. Certain Protozoa, such as *Domatomonas*, *Codonella*, *Strobilidium*, *Strombidium*, and *Cyclidium*, may appear, but never abundantly. Farther downstream, various species of *Chrysococcus*, *Cryptomonas*, *Chroomonas* and *Dinobryon* are found in large numbers where the water is approaching purity. Plankton is scarce except for diatoms and these last-named forms in streams that receive no organic pollution of any sort.

It is apparent that domestic sewage acts as a fertilizer for aquatic plants in the same manner as organic matter does for land plants. The carbohydrates and proteins in fresh sewage are not equally available for all plant growth and meet the nutritional requirements of different organisms in succession during the series of changes leading to inorganic end products. The order of development of the various species of planktonts depends upon their reaction to the concentration of these various products. *Chrysococcus* and *Cryptomonas* are found in the cleaner portions of watercourses low in organic matter. Many species of *Euglena* prefer polluted streams (rich medium) where purification of the sewage has not approached completion. *Pandorina* and *Trachelomonas* may be considered as intermediate forms, preferring culture media of lower organic concentration. So, in the natural course of events, the highest population of plankton occurs at some distance below the source of pollution, where the concentration of soluble materials is suitable for the largest number of species.

Fish life increases in regions where the heaviest plankton populations occur. The plankton furnishes food directly for many larva and some adult fishes and also for water fleas, rotifers, etc., which are important foods for larger fish. The phytoplankton, through the process of photosynthesis, produces oxygen which may be of considerable importance in maintaining a high dissolved oxygen concentration. The coarse fishes are found nearest the source of pollution and game fish appear farther downstream.

Beside the presence or absence of sewage, the plankton population is influenced by temperature, hydrogen-ion concentration, turbidity, variations in stream flow, and seasonal changes. Plankton develops more rapidly at higher water temperatures, while sudden temperature drops reduce the plankton population. At temperatures of 10° C. or lower, a large proportion of the plankton organisms disappear. Certain species will withstand lower temperatures better than others.

Chrysococcus can be collected when the stream is frozen over. Variations in the hydrogen-ion concentration between pH 6 and 8.5 seem to have little, if any, effect on plankton. Lower pH values (4 or less), resulting from acid pollution, may destroy all plankton except a few resistant species (1).

A sudden rise following rain will often flush out plankton, and several days may elapse before the organisms again appear in numbers. High turbidity following rain is also detrimental to plankton. A slow-moving stream which gives more time for bacterial action is more suitable for the development of plankton organisms than a rapid stream. Pool conditions during low flow may result in the development of a large number of certain species not normally present in such numbers. These may be distributed several miles downstream by increased flow following rains. Conversely, a rain may wash the plankton out of a swamp or ox-bow lake into the main stream, thereby causing a sudden increase in the amount of plankton. The constant flow of a stream will carry plankton a distance downstream, and a peak in the plankton population may slowly travel the entire length of the stream.

In the discussion to follow, the effects of pollution introduced directly or indirectly by man will be considered from the stand point of the changes in food supply and the various "ecological niches" along the watercourse. Only the protozoan and normal algal constituents of the plankton will be considered, together with the fish.

METHOD AND PROCEDURE

The majority of the plankton samples were taken with those for the chemical and bacterial studies, by collecting 250 millimeters of water a short distance below the surface. Samples were taken once each week at certain key points along the Ohio River and its tributaries, while at other points samples were taken only once, or at irregular intervals. Samples were brought to the Cincinnati laboratory either fresh or preserved in 4 percent formalin. One hundred cubic centimeters of the water was centrifuged for 5 minutes at a speed of about 2,500 revolutions per minute. The supernatant liquid was decanted, leaving the organisms originally present concentrated in about one cubic centimeter of fluid, the exact amount being determined by a pipette delivering 25 drops per cubic centimeter. The number of organisms in one-fourth of the "catch" was determined by counting under the low and high powers of a compound microscope. The number of organisms was computed per cubic centimeter of the original sample. For a detailed report of the method, see Lackey (2).

The results of the plankton determinations are given in the tables in numbers per milliliter for the various taxonomic groups. The plankton volume is expressed in thousands of parts per million (M. p. p. m.). Volumes were determined by multiplying the number of individuals of the various species by the volume of an average individual of the species. These average volumes were obtained from figures of Lackey and Kehr (unpublished). The volume curves in the graphs are subdivided to show the proportion of class I, class II, and intermediate organisms. Class I organisms are those which tend to favor water of good sanitary quality and are able to survive scarcity

of organic food, sudden changes of and low temperatures, and relatively high acidity. In this class are included such genera as *Chrysococcus*, *Cryptomonas*, *Dinobryon*, *Chromulina*, and the various genera of diatoms (Bacillarieae) encountered. Class II is made of those forms which favor a rich nutritive medium or feed upon bacteria and solid particles. In this group are included *Euglena*, *Lepocinclis*, *Phacus*, *Synura*, *Anabaena*, and the bacteria-eating ciliates such as *Paramecium*, *Colpidium*, *Vorticella*, etc. All plankters not definitely falling into the above extreme groups are lumped together as intermediates.

It is clearly realized that these genera are not homogenous but that certain species differ in their food requirements and tolerance to environmental conditions. Owing, in many cases, to the inability to determine species in formalin-preserved samples, it was considered more advantageous to keep the above grouping and to note particular cases where inconsistencies may be due to species differences. The principal example is *Euglena mutabilis*, found in abundance in acid streams which are free of organic pollution, which would indicate that it belonged to class I. Likewise, *Stephanodiscus*, found in the Wabash Basin, has a distribution which would indicate that it belonged to class II. In these studies, however, these exceptions were not separated from their taxonomic groups, *Euglena* and the Bacillarieae, respectively.

Fish collections were made where possible in the upper and lower thirds of the watershed by means of seines and a trap net (fyke net). No fish collections were made during the season of 1939 in the middle third of the basin. Whenever fish collections were made, plankton and chemical samples were taken. Information on fish life was obtained whenever possible from local fishermen and residents. Results of the biological studies have been compared and correlated in this report with the chemical and bacteriological findings.

In the following discussion, certain terms will recur repeatedly. Pollutants shall be defined as any material introduced into the stream from without, usually of an organic nature. The symbol "D. O." refers to dissolved oxygen, measured in parts per million by the Rideal-Stewart and azide modifications of the Winkler method. The term "B. O. D." (biochemical oxygen demand) refers to the amount of oxygen disappearing from a sealed sample of water at 20° C. in the course of 5 days (due to microorganismal action), and is usually expressed in parts per million. Alkalinity is a measure of the carbonate and bicarbonate buffering capacity of the water, determined by titration with dilute sulfurice acid using methyl orange indicator. Hydrogen-ion concentration is expressed in the usual pH units. Turbidity was determined by the Jackson turbidimeter and is given as parts per million. "Coliform organisms refers to bacteria of the coli-aerogenes group, given in most probable numbers per milliliter. These determinations follow the procedure given in Standard Methods of Water Analysis (America Public Health Association, eighth edition, 1936). The azide modification of the Winkler D. O. determination is that of Ruchhoft, Moore, Placak (3).

The figures following the word "mile" refer to the mileage from the junction of the tributary in question with the Ohio River, except the White River, where the mileage given is taken from its junction with the Wabash River. The mileage on the Ohio River is taken from the confluence of the Allegheny and Monongahela Rivers at Pittsburgh.

EXPLANATION OF FIGURES

On curves showing volume of plankton in thousands of parts per million (M. p. p. m.) the upper line represents the total volume, the space between the upper and middle line represents the volume of intermediate organisms, the space between the middle and lower line represents the volume of class II organisms, and the lower line represents class I organisms.

Drainage Basin Summaries

The biological data collected during the Ohio River Pollution Survey are discussed briefly in summaries covering the individual tributary drainage basins and the main Ohio River. The tributary summaries have been grouped in the middle, upper, and lower thirds of the Ohio River Basin and are discussed in that order. The middle third tributaries are discussed first, as the first year of study was spent in this area and many more samples were examined than was possible in the case of the upper and lower thirds. The Scioto River in the middle third is discussed in appendix I, and the Tennessee River in the lower third is discussed in appendix II. The Beaver River in the upper third was not covered, due to time limitations.

MIDDLE THIRD

Miami River.—The Miami River rises in the west-central part of Ohio in Logan County, near the village of Bell Center (elevation 980 feet). The stream starts as a small brook, meandering through a wide valley, and flows the short distance to Indian Lake, the largest body of water within the State. From Indian Lake, the stream continues in a westerly direction to Dayton (90 miles), where it is joined by the Mad and Stillwater Rivers. At Dayton the direction of flow shifts toward the southwest corner of Ohio. The Miami is joined by the Whitewater River of Indiana at a point 4.8 miles from its mouth and thence flows into the Ohio River near Cleves, at the Ohio-Indiana State line.

The Miami Basin comprises a total area of 5,385 square miles, of which 1,590 square miles are in the Whitewater Basin, mostly in Indiana. Flood-control dams have been constructed at Englewood on the Stillwater, at Phoneton on the Miami above Dayton, and on the Mad River above Dayton.

The northern part of the basin is level to gently rolling; the soils are rich, and agriculture is prosperous. The southern part is more eroded, the slopes are steeper and soils less fertile than in the northern part. The rocks which underlie the basin are limestone and shale. The average slope below Middletown (mile 53.6) is about 3.6 feet per mile, and the maximum and minimum discharges at the mouth of the river are 478,000 and 340 (summer minimum at Hamilton) cubic feet per second, respectively.

The population of the Miami Basin was about 830,000 in 1940. Over 60 percent of the population was urban and 10 percent more lived in incorporated towns of less than 2,500. The population density was about 155 per square mile, considerably above the average for the entire Ohio Basin. The population density of the Indiana portion of the basin was about 75 and the Ohio portion about 183 per square mile.

The principal cities in the Miami Basin are Dayton, Springfield, Hamilton, Middletown, and Piqua, Ohio, and Richmond and Connersville, Ind. The total population of these towns is 427,286 (1940), which is more than half the population of the basin. All of these cities are industrial and manufacturing centers. The principal products are paper, machinery and tools, sheet metal, and textiles.

In order to study the seasonal distribution and variation of plankton, a series of samples was taken at Cleves at weekly to biweekly intervals, from May 16 to December 12, 1939. The results are shown in figure 2 and table 1. The first sample was taken on May 16 when the turbidity was low (about 10 parts per million). The plankton volume was high, largely due to diatoms. The high dissolved oxygen value of about 10 parts per million is, in all probability, due to the large plankton population. During the 6-week period between this date and June 26, more than 3 inches of rain fell. Owing to the high turbidity, plankton samples were not taken. On June 26 the water had cleared sufficiently to continue plankton examinations. The total plankton volume was low, due, no doubt, to previous high turbidity and the flushing out of the stream by the frequent rains. This was reflected in the low coliform organism count and low biochemical oxygen demand.

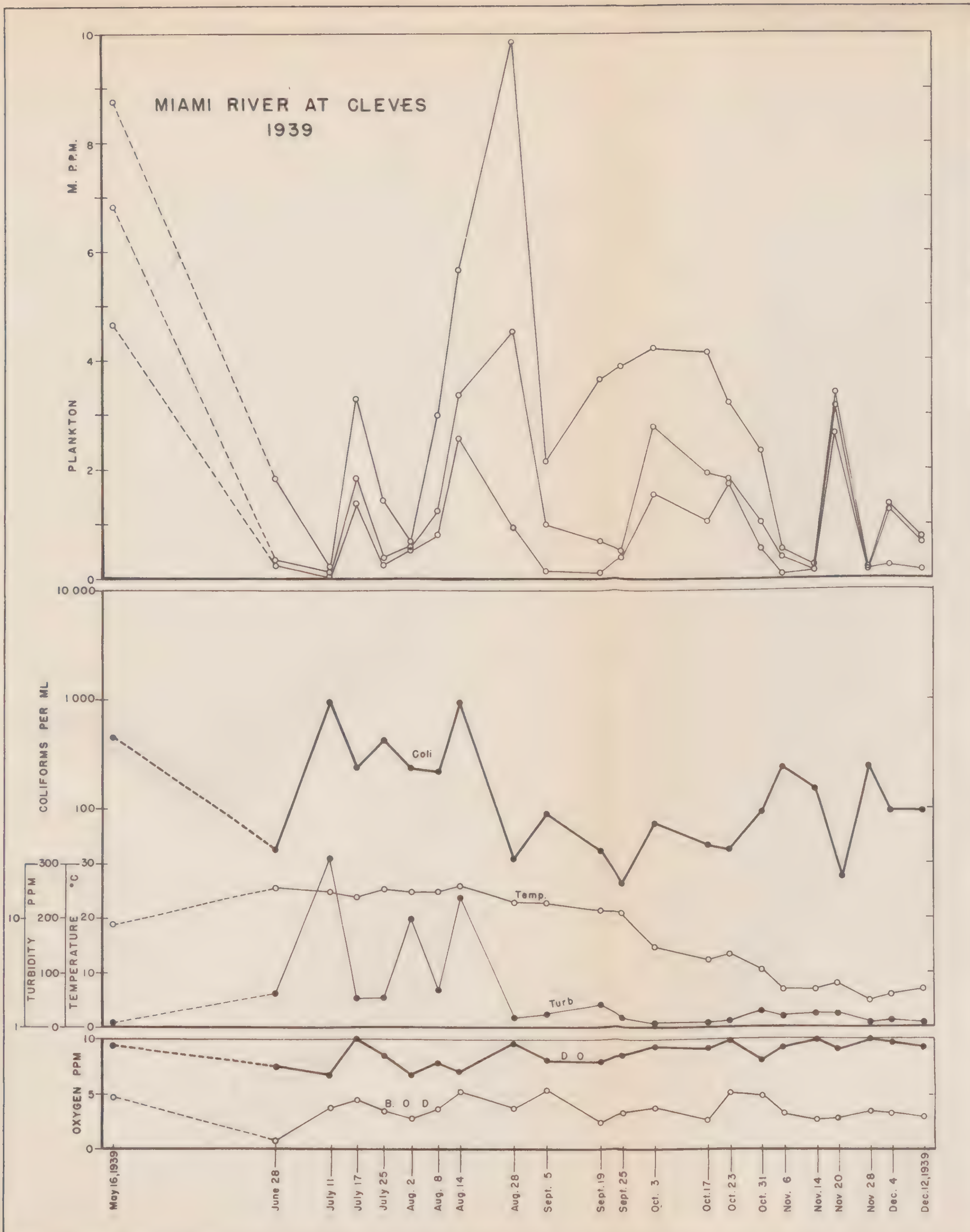
On July 11 the turbidity was again high, due to previous rains, and the plankton was washed out of the river. July 17 showed a slight recovery of plankton, accompanied by a drop in turbidity. The plankton population again started to rise on August 2, reaching the highest value of the summer—about 10 thousand parts per million—on August 28. Rain on September 4 may have influenced the drop in the plankton population.

The plankton rose slowly to about 4 thousand parts per million in the next several weeks, until the advent of cold weather. The temperature dropped to 12° C. on October 17 and continued falling to 7° C. on December 12. This resulted in great depression of the plankton population other than diatoms. During this period the river was in a stable condition as light rains fell only occasionally.

A series of samples was collected at various stations from Cleves to Miamisburg at intervals from June 27 to October 26. The results are plotted in figures 3 and 4. The figures indicate that there is a strong tendency for the dissolved oxygen and the biochemical oxygen demand to vary inversely, and for the biochemical oxygen demand and the number of coliform organisms to vary in the same direction. Exceptions occur after the middle of August, a majority of which may be fairly readily explained.

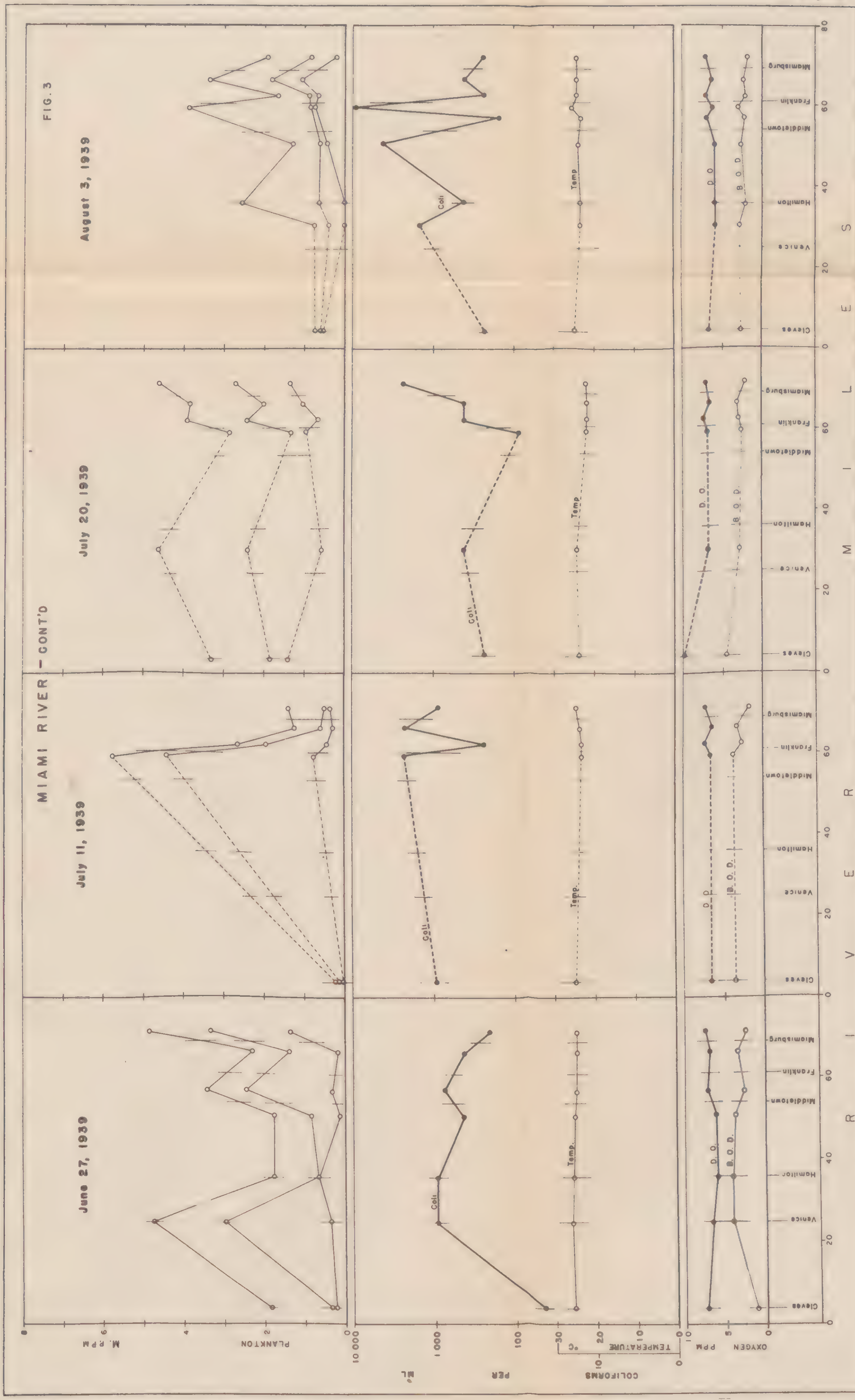
Thus the unexpectedly high dissolved oxygen values found along the river on August 17 seem to be attributable to the high plankton volumes of that date. This relation of the plankton to dissolved oxygen is also indicated at stations above Middletown and near Troy and Piqua on the upper river on September 14. The erratic values for August 31 cannot be readily explained. It should be pointed out, however, that after July the river was in low-flow "pool" condition, the characteristics of a stream at low water being quite different than during high water.

A further element complicating the coliform organism-biochemical oxygen demand-dissolved oxygen relationship at this season is the introduction of organic industrial wastes, which have high biochemical



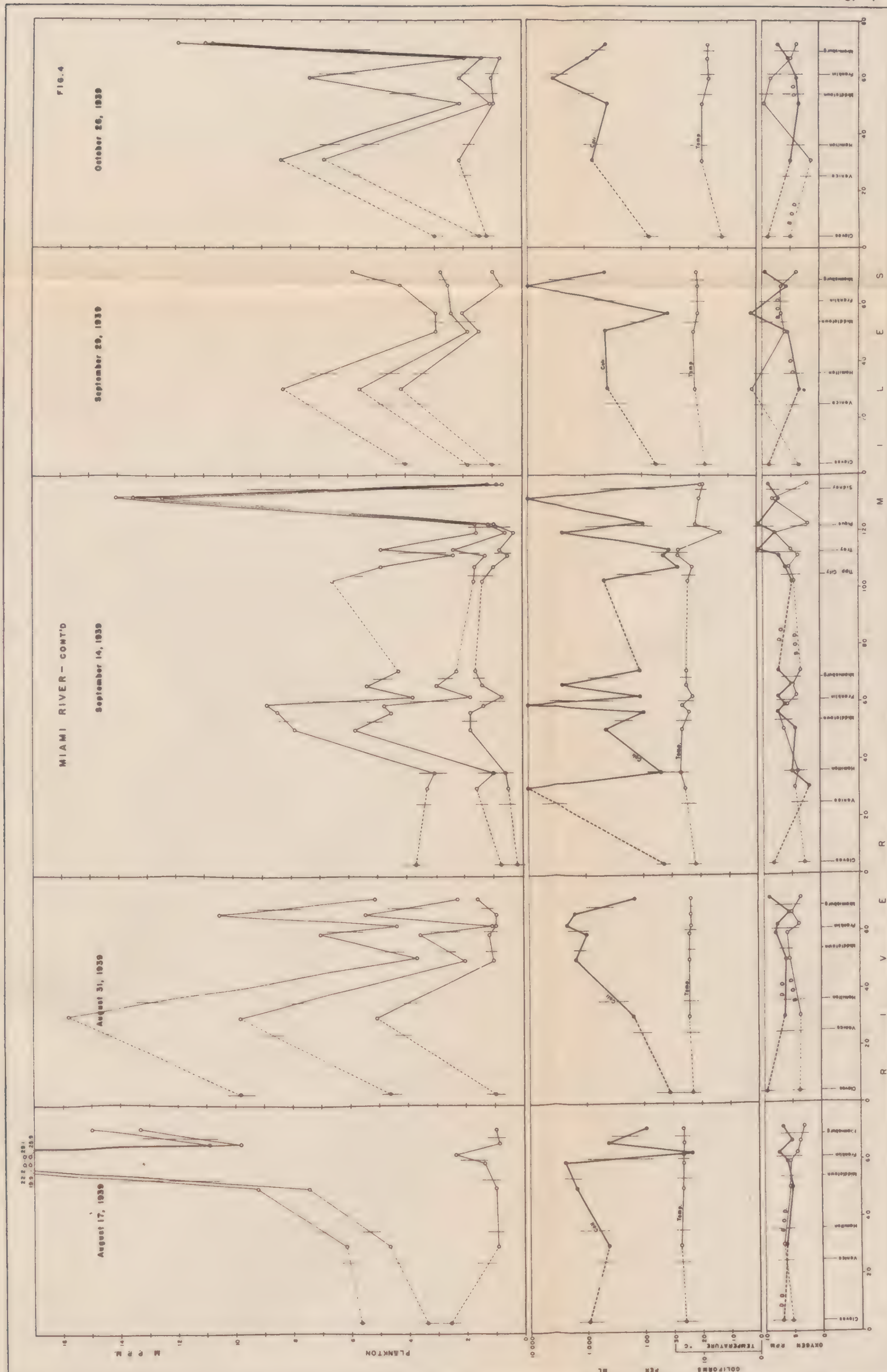
MIAMI RIVER AT CLEVES
1939
PLANKTON M. P.P.M.
COLIFORMS PER ML
Coli
Temp.
Turb
TURBIDITY PPM
TEMPERATURE °C
OXYGEN PPM
D O
B. O D
May 16,1939
June 28
July 11
July 17
July 25
Aug. 2
Aug. 8
Aug. 14
Aug. 28
Sept. 5
Sept. 19
Sept. 25
Oct. 3
Oct. 17
Oct. 23
Oct. 31
Nov. 6
Nov. 14
Nov 20
Nov 28
Dec. 4
Dec. 12,1939

Fig. 3



(NOTE.—For explanation of figures see p. 1287.)

FIG. 4



(NOTE.—For explanation of figures see p. 1287.)

oxygen demand values in the stream, are not accompanied by coliform organisms, and have a variable availability as food for the plankton. Cannery wastes may be mentioned as typical of this class of pollutants. Such material may account for the high biochemical oxygen demand observed below Hamilton on September 29, as well as other discrepancies noted in the curves. Certain other irregularities, such as the dissolved oxygen peak at Franklin on September 29, are not at present to be explained. The unpredictably high dissolved oxygen value at Cleves on October 26 is presumably related to the lower water temperature and greater oxygen solubility at the lower temperature. Other oxygen differences, such as the absence of a sharp oxygen peak at Sidney, September 24, to correspond with the plankton peak, may be due to the difference in composition of the plankton compared with the plankton further downstream (diatoms instead of flagellates of various kinds).

There are certain fairly definite seasonal and weather influences affecting the plankton. Summer warmth, sunshine, and low water tend to increase the plankton population, aided by the low turbidity of this season. Rains tend to wash out the stream and deplete the plankton (the curve of August 3 shows the condition following heavy rain) and low or rapidly dropping temperatures take heavy toll of the less resistant planktont. In addition to these general factors, a stream such as the Miami shows characteristic effects of the various sources of pollution along its course.

Hamilton, with a sewered population of 54,600, no sewage treatment plant, and many industries—coke plant, textile mill, meat packing house, paper mills, and several creameries—tends to raise the volume of the river plankton, with the peak occurring farther downstream, as at Venice, and class II organisms form a large portion of the plankton.

Middletown, with a sewered population of 35,000 and no sewage treatment plant, has a number of paper mills, and it is probably the effect of this heavy load of industrial waste that causes a sharp local depression of the plankton volume. During summer conditions this depressive action may not be well marked. The peak of the Middletown fertilization effect probably comes somewhere in the vicinity of Hamilton.

Franklin is a smaller town, having a sewered population of 4,000 and several paper mills. The town has a secondary sewage disposal plant under construction (1939). In general, there is a rise in the plankton population immediately below Franklin. The only exceptions to this occur in the series of July 20 and September 29. The factors involved here are not known.

Miamisburg has a sewered population of 5,300, two paper mills, and a tobacco plant. The absence of a sewage disposal plant is shown in the lowering of the plankton population of the Miami River as it passes the city. Exceptions to this generalization are shown in the curves of August 3, 31, and September 14. The reasons for this are not clear, but it may be pointed out that this is the period of low water and slow flow, and Miamisburg is a relatively small town.

Of the upstream samples included in the figure for September 14 (fig. 4), Tipp City, with a secondary sewage treatment plant under construction (1939) to serve 2,500 people, raised the plankton volume; Troy, with a chemical precipitation sewage plant under construction

to serve 9,800 people, depresses the plankton population; Piqua, with a chemical precipitation sewage plant under construction (1939) to serve 15,800 people, and with a brewery, a cannery, and a meat packing house, causes a slight depression of the plankton recorded at that location.

Sidney has a sewered population of 9,500, but no treatment plant. In addition, creameries, a brewery, and a meat packing house supply a heavy industrial load. The meaning of the sharp peak of diatoms at this point is not clear. It may be indicative that one genus of diatom in particular is involved, *Navicula*.

The heavy plankton noticeable in the samples from above Miamisburg, resulting in a considerable volume of class II planktonts below Miamisburg, in addition to the contribution from that city, must be attributed to the influent from the Dayton urban area, at about mile 85.

The flora and fauna of the Miami are abundant in species and numbers. This is especially true at all stations below Dayton and is due without doubt to heavy pollution load from the cities situated along the stream. These communities are discharging wastes into the stream at close intervals. The river does not recover from one heavy pollution loading before the next load of pollution is received. It is, therefore, difficult to study any one city separately and determine to what degree it affects the stream.

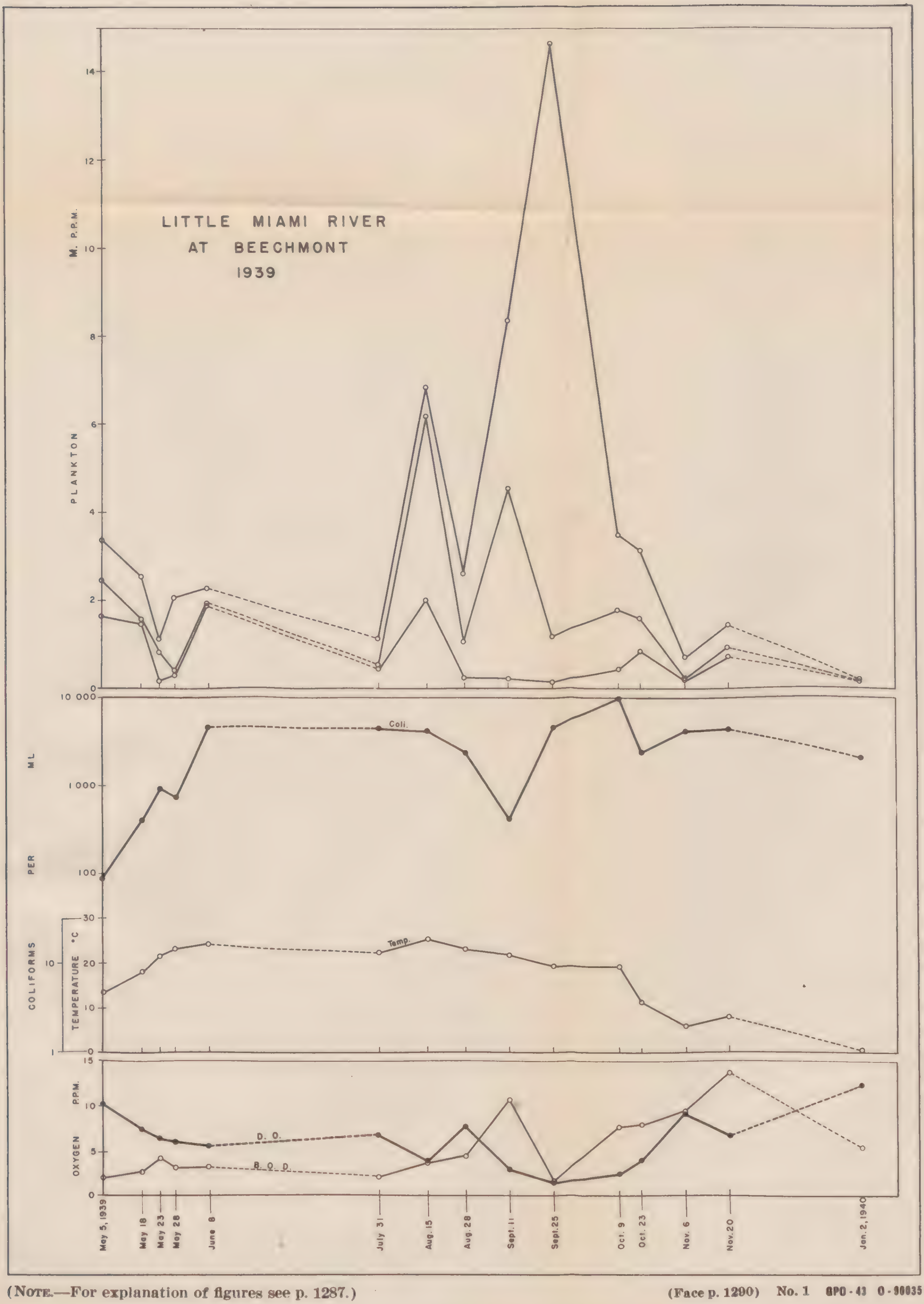
Samples collected during July and August indicate that the Mad River, which joins the Miami above Dayton, is a clear stream, as shown by the lack of organisms other than diatoms. Good trout fishing is reported in this stream at West Liberty. The Stillwater, another tributary which joins the main stream at Dayton, shows heavy pollution at Englewood, where a sample was taken on July 24. This may be due to accumulation of end products from the sewage of towns farther upstream. Twin Creek and Seven Mile Creek, which are clear tributaries, enter the Miami at Franklin and Hamilton, respectively. Four Mile Creek, which is polluted at Oxford, enters the Miami at mile 38.0.

The Whitewater River, which enters the Miami above Cleves, contained large numbers of *Euglenophyceae* below Harrison, and in the East Fork above Brookville.

Little Miami River.—The Little Miami River has its source in Clark County, Ohio, southeast of Springfield, and flows in a southwesterly direction for 100 miles. It joins the Ohio River within the city limits of Cincinnati, Ohio. The entire drainage basin lies southeast of the Miami watershed and drains an area of 1,755 square miles. The headwaters have an elevation of 1,150 feet and the river grandient averages about 6.5 feet per mile.

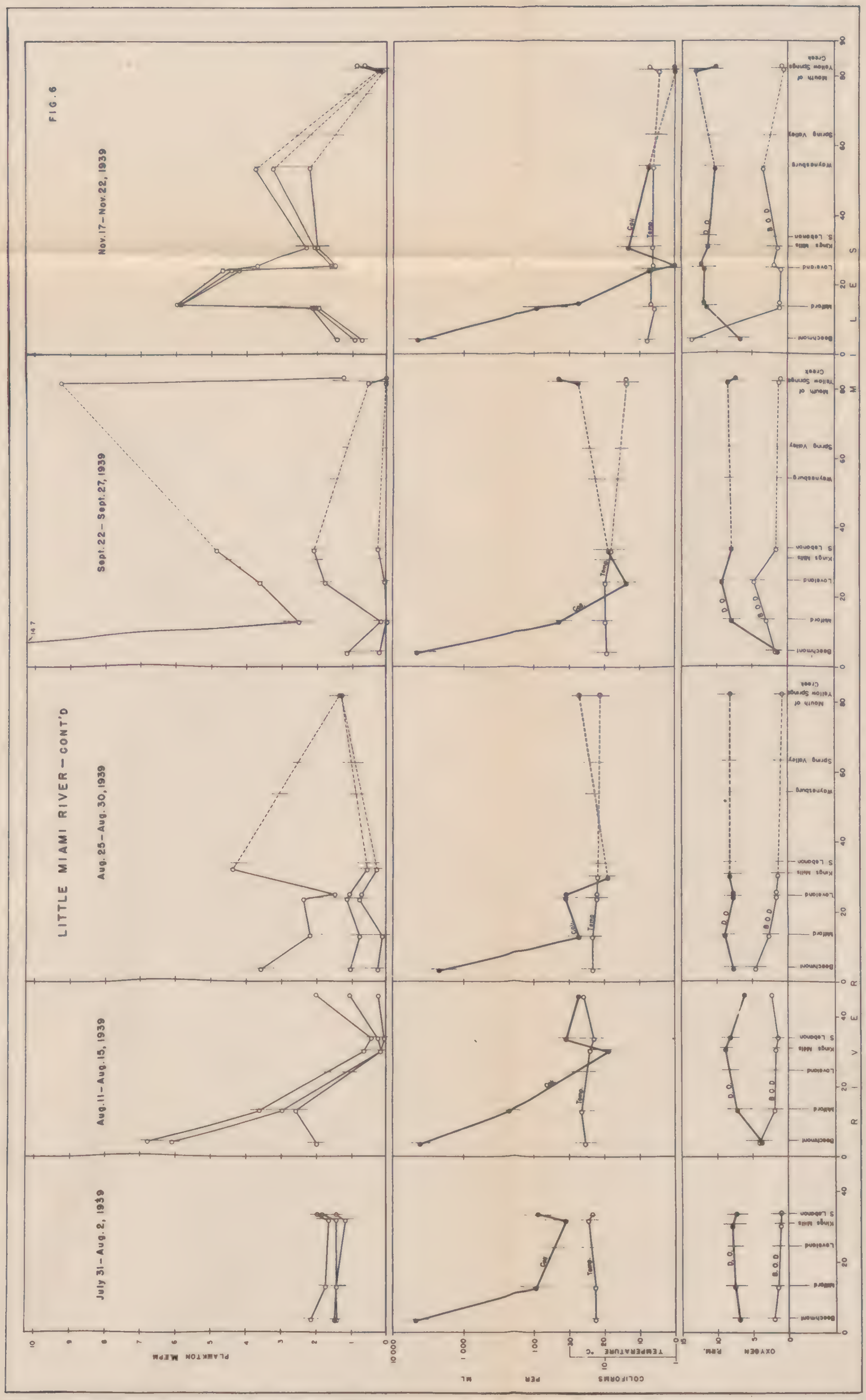
Agriculture is the chief industry throughout the Little Miami Basin. Very little manufacturing is done. Seasonal canning of truck crops, with the waste products entering the river, creates a definite stream-pollution problem. The total population of the basin, excluding part of the Cincinnati area, was 135,474 in 1940, of which 24,004 reside in the 41 incorporated communities. The principal communities are Xenia (population 10,633), Wilmington (population 5,971), and Lebanon (population 3,890).

A series of samples was taken at Beechmont on the Little Miami River from May 5 to November 20, 1939, with the exception of a



(NOTE.—For explanation of figures see p. 1287.)

FIG. 6



(NOTE.—For explanation of figures see p. 1287.)

period between June 8 and July 31, at which time heavy rains occurred (fig. 5 and table 2). The biochemical oxygen demand was consistently low until Ausgut 15, at which time it showed a slight increase, reaching a peak on September 11, during the low water period. An unexplained drop occurred September 25, followed by a consistent rise up to November 6. A slight drop occurred on November 20. The dissolved oxygen also showed a decided drop to 3 parts per million on September 25, followed by a constant rise up to November 20, at which time it reached the peak of the season due to low temperature at that time. The coliform organism curve is very uniform along the river from July 31 to November 22.

During the period from July 31 to August 2 the small towns along the stream seemed to have no effect on the plankton population (fig. 6 and table 2). During the rest of the season, however, the plankton dropped below South Lebanon and there followed, in most cases, a gradual rise to the mouth at Beechmont. However, on November 17 the plankton showed a decided drop below Milford.

During the week of September 22-27 a tremendous rise in the plankton occurred below the mouth of Yellow Springs Creek, due, no doubt, to a heavy pollution load from Yellow Springs.

A series of samples was taken along the East Fork and Turtle Creek, important tributaries of the Little Miami. Batavia and Waynesburg (secondary sewage treatment plant since constructed) discharged a small amount of untreated sewage in the East Fork, which, however, is not sufficient to cause a decrease of plankton but keeps the stream fertilized. Turtle Creek shows clearly the effect of heavy pollution on the plankton of a small stream and the rate of recovery of such a stream. The heavy discharge of sewage from Lebanon (chemical precipitation sewage plant since constructed) on July 19, August 2, and October 22, destroyed most of the phytoplankton in the stream immediately below town, but the plankton was present at South Lebanon about 3.5 miles further downstream.

The same condition occurs on Shawnee Creek. Below Xenia on August 25 it was observed that most of the plankton except the diatoms, *Cyclotella* and *Navicula*, were destroyed. A possible discharge from the heavily overloaded treatment plant may have been the cause. The contrasting plankton population of Lytle Creek, below Wilmington, may be due to the chemical precipitation treatment plant.

Licking River.—The Licking River rises in the mountains of southeastern Kentucky in Magoffin County, flows in a northwesterly direction across the State and joins the Ohio River between Covington and Newport, opposite Cincinnati, Ohio. The total length is about 320 miles, with a watershed area of 3,670 square miles. Its average slope below Farmers (mile 172.5) is 1.2 feet per mile.

The upper portion of the Licking Basin lies in the mountains. The remainder is in the Bluegrass region. The underlying rocks are principally sandstone, shale, and coal. The population of the mountainous region has a density of about 42 per square mile. There are only 4 incorporated towns in this section, the largest being West Liberty, with a population of 573 (1940)

Morehead (population 1,901) and Farmers (population 296) are the only two incorporated towns in the transition zone between the mountains and the Bluegrass. The Bluegrass section is gently rolling and highly fertile. Four urban communities are in this area: Winchester

(population 8,954), Paris (population 6,697), Cynthiana (population 4,840), and Mount Sterling (population 4,782).

Samples at the mouth of the Licking River (Latonia) were taken from May 3 through November 13, 1939. The highest values observed for plankton were during the period from the middle of September to the middle of November (fig. 7, table 3). The September peak was composed largely of the diatom, *Cyclotella*, while the peak of November 6 is due mainly to *Chlamydomonas*. Large numbers of *Chrysococcus* were found on November 13.

The depression in the plankton curve on May 25 is due to heavy rains between May 17 and May 25. This is accompanied by an increase in the coliform organisms that may have been washed into the river. The coloform count was very low for the remainder of the period of observation. The biochemical oxygen demand values were all below 2.5 parts per million, and the dissolved oxygen curve seems to follow the influence of temperature more than any other single feature. The nearest point of any considerable pollution on the Licking River is a creamery plant at Falmouth, which is some 50 miles up the river.

Samples were collected on the Licking River from Falmouth (mile 51) to Farmers (mile 172.5). Clayville (mile 82) appears to be a source of slight pollution. The stream also shows some contamination from Blue Lick (mile 100). Fleming Creek, entering a few miles above Blue Lick, is heavily polluted below Flemingsburg, but seems to have recovered before entering the Licking. The large numbers of *Chrysococcus* in the headwaters above Farmers and in many of the smaller tributaries indicate that these streams are comparatively free from domestic pollution. Some of the smaller creeks (runs) at Salyersville are contaminated with acid mine drainage.

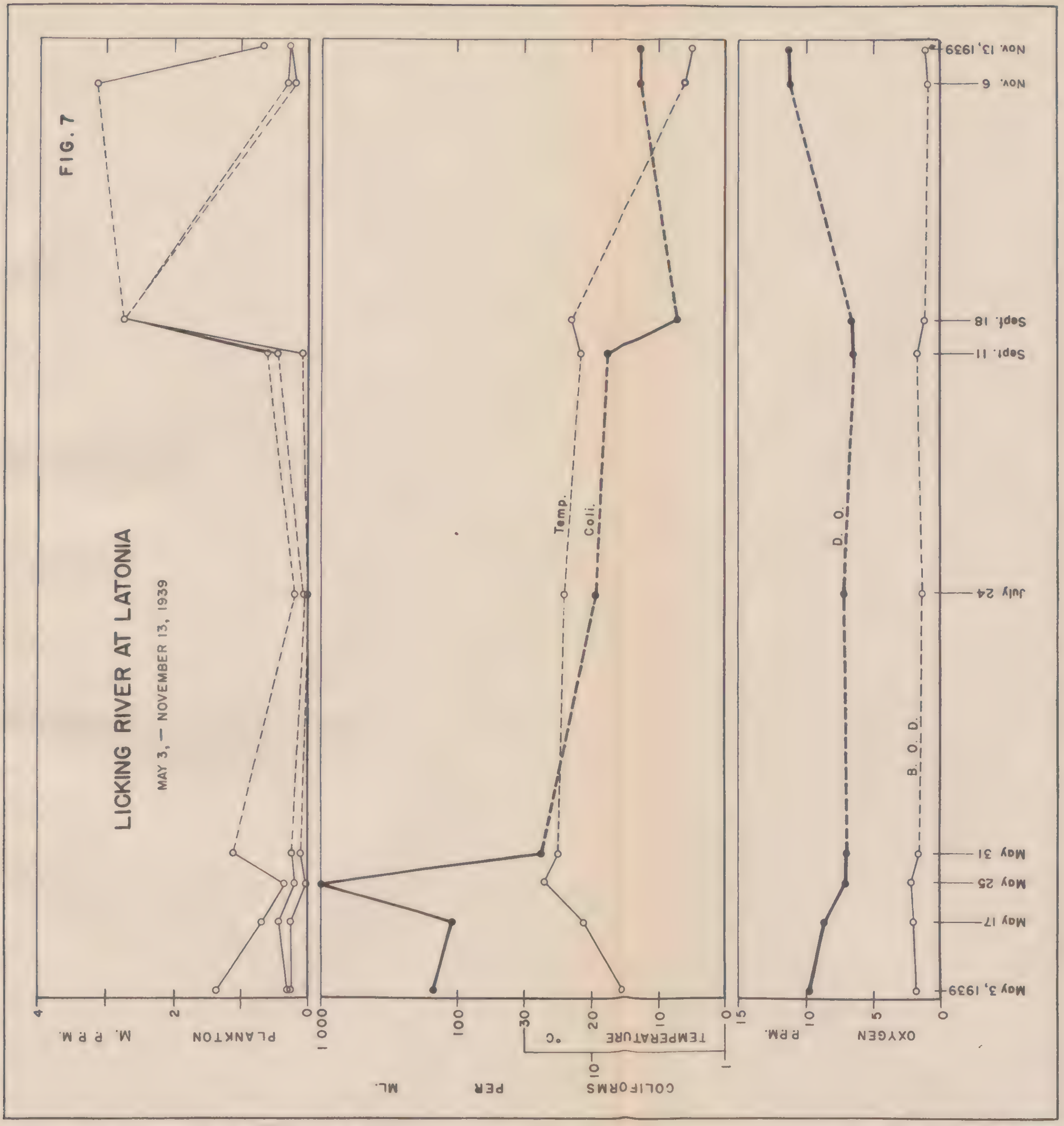
The South Fork was studied by examination of samples collected at Falmouth (mile 51), Cynthiana (mile 82), and Lair (mile 87). The results indicate that these towns are sources of heavy pollution. Hinkston and Stoner Creeks are heavily polluted (septic) below Mount Sterling and Paris (secondary treatment plant under construction 1939), respectively.

A study of the fishes of the Licking River was made by Welter (4). He lists a total of 70 species, mostly minnows, shiners, catfish, and suckers, which are widely distributed in the upper region of the watershed. Various species of bass and sunfish are reported from the main stream at Farmers and Triplet and from Fleming and Beaver Creeks.

Kentucky River.—The Kentucky River rises in the mountainous region of the southeastern portion of Kentucky and flows in a general northwesterly direction to its junction with the Ohio River at Carrollton. The river is formed by the confluence of the Middle, North, and South Forks near St. Helena, in Lee County. The three forks rise in Clay, Leslie, and Letcher Counties, respectively, which lie in the Cumberland Plateau near the Virginia border. The length of the main stream from Carrollton to the junction of the North and Middle Forks is 259 miles. The watershed area is 6,940 square miles. The average slope below Beattyville (mile 255) is about 0.9 feet per mile.

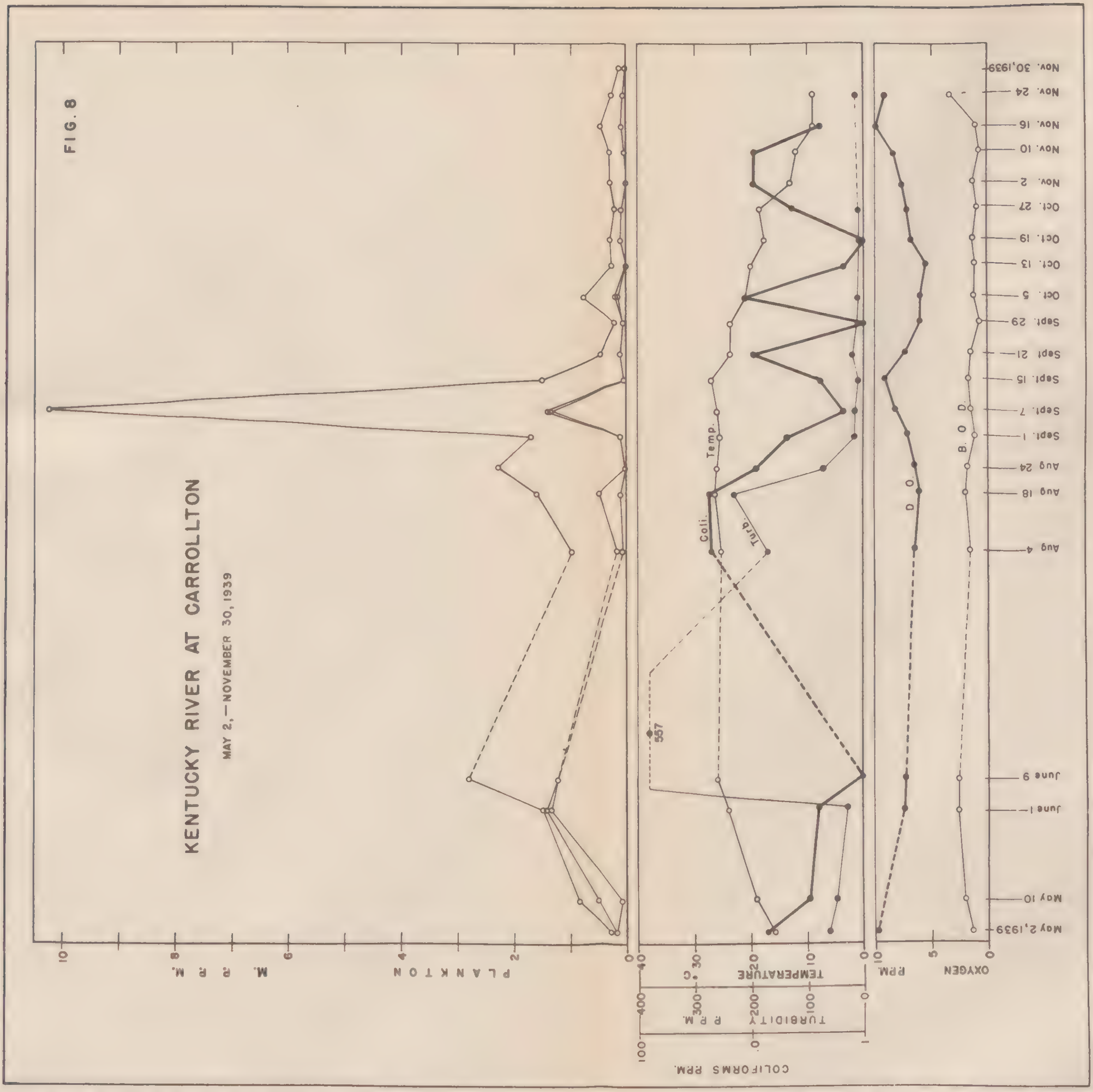
The Kentucky River headwaters are located in an important coal region. Many of the smaller tributaries are heavily polluted with acid drainage from coal mines, giving the water and bottoms of the streams

Fig. 7



(NOTE.—For explanation of figures see p. 1287.)

Fig. 8



(NOTE.—For explanation of figures see p. 1287.)

a rusty appearance. This region is subject to heavy rains during the summer, and flash floods are common.

The river has carved a deep gorge of unusual beauty through limestone and shale for many miles of its course, forming the "Palisades of Kentucky" at High Bridge, 117 miles above Carrollton. The mountainous region gives way to beautiful rolling hills forming the well-known Bluegrass region around Lexington, through which the river meanders to the Ohio. The fertility of the soils is due to the phosphate nature of the limestone from which the soils are derived.

Population distribution is determined by the geological characteristics of the basin. There are many scattered towns of a few hundred inhabitants in the coal region, but the largest concentration of population is located in the Bluegrass region around Lexington which has a population of 49,304 (1940). Frankfort (population 11,492), the State capital, is located on the river, 66 miles above its mouth.

The Kentucky River has been improved for navigation by the construction of 14 locks and dams from Carrollton to Beattyville.

A series of samples was taken at the mouth of the Kentucky River at Carrollton, from May 2 through November 30, 1939 (fig. 8 and table 4). From June 9 through September 1 the river was in a very turbulent condition and only a few samples were taken. Following the 1st of September, the turbidity remained at a low level. The numbers of coliform organisms found at the sampling point were extremely low. The biochemical oxygen demand approached 3 parts per million before the turbidity increased in the late spring, and was in the neighborhood of 2 parts per million at certain times during the summer, showing no correlation with the numbers of the coliform organisms. It is interesting to note that considerable plankton was found in the stream even at times of rather high turbidity. There was a sharp peak of plankton about September 7, due, for the most part, to a bloom of large *Pandorina*, which quickly disappeared. At the termination of this bloom the plankton sank to 0.05 thousand parts per million or less and remained at this low level for the rest of the period of observation. The plankton curves give an impression that a limited amount of nutrient material was present and was exhausted by the bloom of *Pandorina* mentioned above.

The usual low level of dissolved oxygen during the hot summer months shows a rise at the time of the *Pandorina* bloom. There is another rise at the advent of lower temperatures which may be ascribed to the greater solubility of oxygen under these conditions.

The Kentucky River shows an almost complete absence of class II organisms, except for early spring, and shows an occasional flare of diatoms. The characteristic features of the plankton in the Kentucky River involve the large numbers of certain class I organisms which are found. Samples from the upper portion of the river, especially of the main branch, show extremely high numbers of *Chrysophyceae*, while samples from certain of the lower portions of the river (Frankfort and below) show large numbers of diatoms. With one or two local exceptions, class II organisms are very scarce.

Good fishing is reported locally on the Kentucky River from Carrollton to Gratz, and considerable commercial fishing is being done at Gratz, 29 miles above the mouth. Several species were reported, such as carp, catfish, pike, bass, and perch. Local inhabitants re-

ported that there are no game or food fishes in the river at Irvine (mile 218).

Big Sandy River.—The Big Sandy is formed by the confluence of Levisa and Tug Forks at Louisa, 27 miles above the mouth. The main river and 94 miles of the Tug Fork form the boundary between Kentucky and West Virginia. The entire basin comprises an area of about 4,280 square miles, of which 2,280 are in Kentucky, 1,015 in Virginia, and 985 in West Virginia. The topography is largely mountainous or hilly, and the underlying rocks are composed of sandstone, shale, and coal. There is considerable coal mining on the headwaters, and acid mine drainage and coal washings are important sources of pollution. The area was originally covered with hardwood forests, but most of them have been cut away. The soils are generally thin and infertile, and the slopes are too steep for successful agriculture. The small amount of good farming land is located along the streams and forms a very small percentage of the total area.

The average slope of the Big Sandy below Louisa is 1.1 feet per mile. The slope of Tug Fork is 12.2 feet per mile near the headwaters. The slope of Levisa Fork is about 1.3. The stream has been improved for navigation by the construction of three dams between the mouth and Louisa, and one dam on each fork.

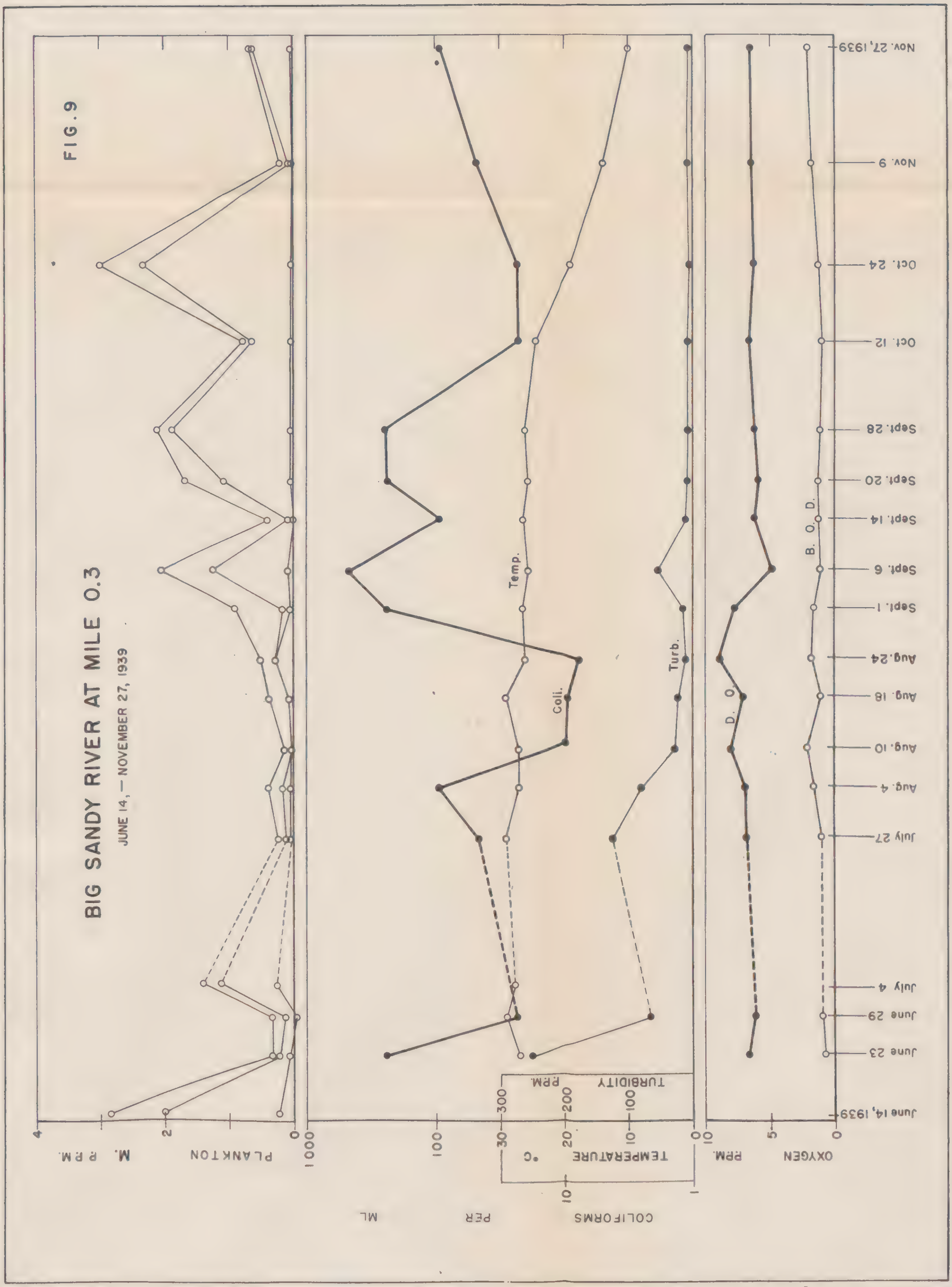
The population of the Big Sandy Basin in 1940 was 411,905, of which 31,185 lived in towns of more than 2,500 people. About 35,000 lived in small incorporated towns, and a large but unknown number were in unincorporated mining camps. The density of population was 97 per square mile.

The important towns along the Tug Fork are Welch, population 6,264 (mile 160), and Williamson, population 8,366 (mile 84). The only town of urban size on Levisa Fork is Pikeville, population 4,185 (mile 115.7).

A series of samples was taken 0.3 miles above the mouth of the Big Sandy during the period from June 14 to November 27, 1939, (fig. 9 and table 5). The biochemical oxygen demand at this location was less than 2.5 parts per million during the entire period of observation. The dissolved oxygen was fairly constant at about 6.5 parts per million following the middle of September, although during the time preceding this date there were some irregularities. During the period of decreasing temperatures, after the middle of October, there was a slight but constant rise in both the biochemical oxygen demand and the number of coliform organisms, which follows inversely the trend of the temperature.

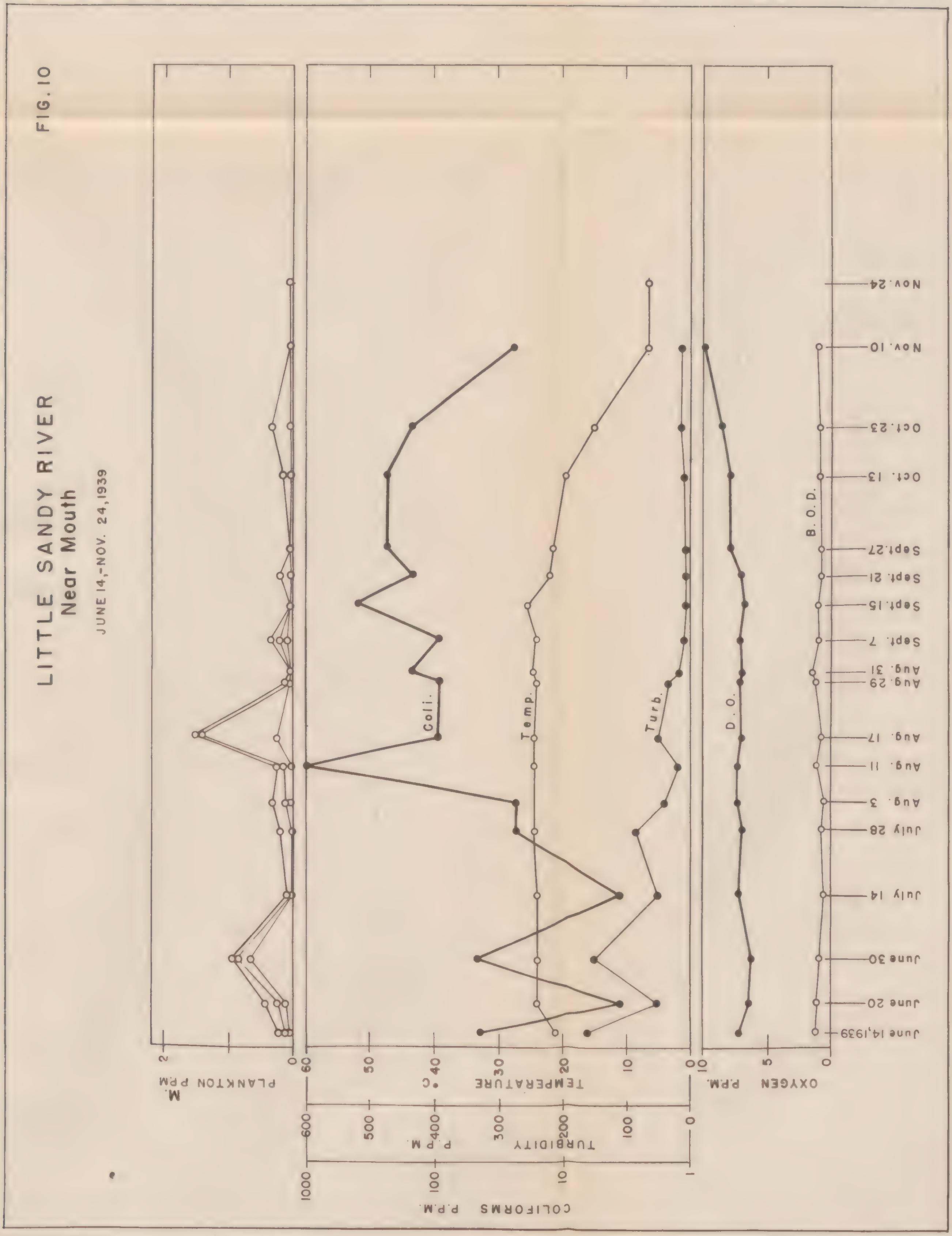
There are several distinctive features of the plankton population at this location. There is an almost complete absence of diatoms, for the most part, and an unusually large and constant volume of class II organisms. The low coliform organism counts are perhaps evidence of the relatively clean nature of the stream at the sampling point. This may be substantiated by the rise in plankton paralleling the rise in coliform organisms from September 1 to October 24. The depression in the plankton curve on October 12 is due to heavy rains which fell generally throughout the basin. The depression at the mouth on September 14 may perhaps be related to rains which fell at scattered points on September 5. There is a noticeable tendency for the plankton to survive after the biochemical oxygen demand and coliform organism values have dropped.

Fig. 9



(NOTE.—For explanation of figures see p. 1287.)

Fig. 10



(NOTE.—For explanation of figures see p. 1287.)

The deficiency of diatoms at this sampling point seems characteristic of the Big Sandy River as a whole, as data from points upstream seem to show. Diatoms are numerous only in that portion of the Tug Fork in the vicinity of Welch and Iaeger. The Big Sandy at the mouth receives wastes from a refinery a short distance upstream but this is apparently not the cause of the local absence of diatoms. Residents report that catfish and carp are present but that their flesh is unfit for food due to the odor and taste of the petroleum constituents.

Samples taken at points in the upper portion of the watershed show a predominance of class I forms except immediately below sources of pollution.

Little Sandy River.—The Little Sandy River lies in the northeastern portion of Kentucky. It rises in the hills of Elliott County, and flows through steep, narrow valleys in a northeasterly direction. It joins the Ohio River below Greenup, Ky. Small coal mines are operated in the headwaters and a number of abandoned mines add acid drainage to many of the small tributaries. Sandy Hook (population 155), and Grayson (population 1,176), are the most important towns on the stream. There are, however, several communities between Sandy Hook and Grayson that empty untreated wastes directly into the river.

Samples were taken at the mouth of the Little Sandy River (mile 0.1) between June 14 and November 24, 1939, and a few were taken above and below Grayson (mile 28) in September, October, and November (fig. 10 and table 6). Until early in August the water of Little Sandy was rather turbid and the biochemical oxygen demand and coliform organism values were low. It is during this period that most of the class II organisms appeared in the plankton samples at the mouth of the river. Commencing with the sample of August 11, there is a rise in the general level of the coliform organisms and, to a lesser extent of the biochemical oxygen demand. In connection with these data for the mouth of the river, it is to be noted that samples in the region of Grayson on September 8 and 22 show fair numbers of class II organisms below Grayson, in contrast to none above the town. Class I organisms, with the exception of *Cryptomonas erosa*, are scarce at the mouth of the river, while the samples in the vicinity of Grayson show considerable numbers of *Chrysococcus* and *Dinobryon*. As there is no consistent difference between the *Chrysococcus* population immediately above and below Grayson and as the stream is swift here, it seems that a certain distance is necessary for the effect of the pollution introduced by the community to be felt in the plankton population.

It is to be noted that in one sample, that of September 8, *Dinobryon* is present in considerable quantity below Grayson, while it is absent above the town. Aside from samples which include an occasional large ciliate, the plankton volume found at the mouth of the river was usually less than 0.5 thousand parts per million. The samples taken in the vicinity of Grayson were of the same order of magnitude.

Guyandot River.—The Guyandot River rises in Wyoming County, southern West Virginia, and flows northwesterly, discharging into the Ohio River at Huntington, West Virginia. The length of the river is about 166 miles. The stream drains an area of 1,670 square miles of hilly and mountainous country between the Kanawha and Big Sandy Rivers. The area is underlaid by one of the largest bituminous coal

deposits in the country. Natural gas occurs in the northern part of the basin.

Below Logan (mile 81) the stream has an average slope of about 1.8 feet per mile, while above Logan the slope averages 11.2 feet per mile. The flow of water is fairly uniform for the lower thirty miles, but above this the stream is a succession of pools and shoals.

The basin is a part of the Allegheny Plateau, and the poor soil and steep slopes make the land unsuitable for agriculture. Less than one-fourth of the land is cleared. The population of the Guyandot Basin in 1940 was 148,257. There are only 10 incorporated towns in the basin and only two of these, Logan (population 5,166), and Mullens (population 3,020), have more than 2,500 people.

Samples were taken at irregular intervals at the mouth of the Guyandot River at Huntington (mile 0.6), from June 14 through November 27, 1939. The stream at this point is practically a pool from the backwater of Dam 28 in the Ohio River. At various times during the summer the water was colored by dye from an industrial plant in Huntington. A very heavy concentration of a blue dye appeared in a sample taken October 24, and the same dye appeared in the Ohio River sample taken below Greenup, Ky. It is difficult at the present time to state the effect of this dye upon plankton. The plankton volume was low during the period of observation. After August 14 it was less than 0.5 thousand parts per million and usually less than 0.3 thousand parts per million (fig. 11 and table 7).

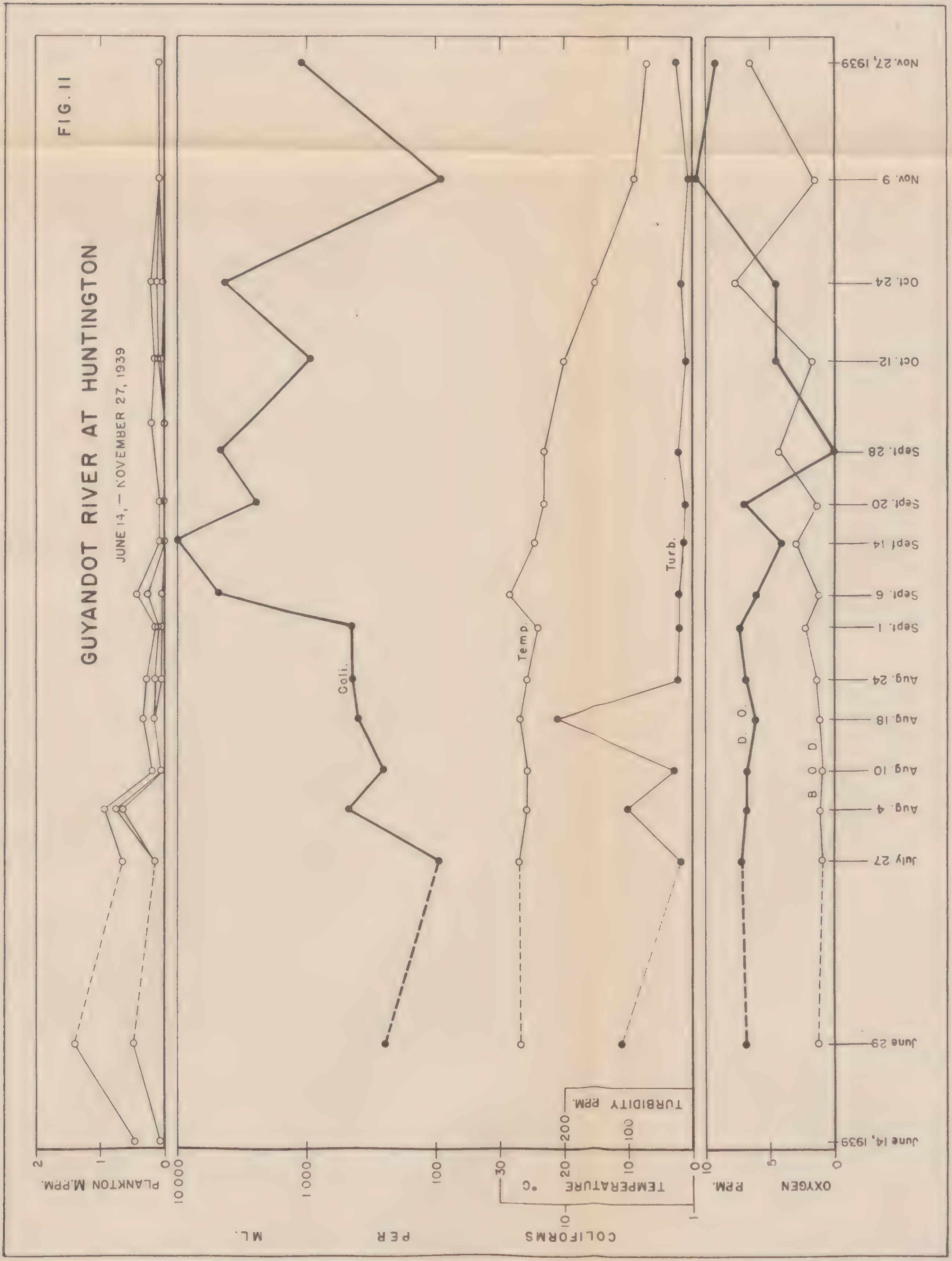
In contrast with the low plankton, the coliform organism count is extremely high and the biochemical oxygen demand also reaches high values. At times of high temperatures and high biochemical oxygen demand, the dissolved oxygen is greatly reduced, reaching the low volue of 0.08 parts per million on September 28.

The three peaks of the turbidity curve coincide with the three slight rises of the plankton curve and may indicate a flushing down of plankton from the higher, less polluted regions of the river. It should be pointed out that the biochemical oxygen demand does not reach the same relatively high values, for the most part, as the coliform organism count, indicating that it is possible to have domestic pollution of a type which constitutes a serious public health hazard without being indicated by a high biochemical oxygen demand.

The stream between Huntington and Gilbert (mile 111.3) contains a high number of *Chrysophyceae*. There was practically no aquatic life in the stream at Pineville, Itman, and Mullens, due to the heavy discharge from coal washeries. In October and November the water was black with small particles of coal. Likewise, the small tributaries in the headwaters, Buffalo, Island and Clear Forks, were devoid of life due to the discharge of coal mine drainage.

Kanawha River.—The Kanawha River, with a drainage basin of 12,300 square miles, is formed by the union of the Gauley and New Rivers in the southwestern part of West Virginia and flows in a northwesterly direction, emptying into the Ohio River at Point Pleasant, West Virginia. The total length from the mouth to the junction of the New and Gauley Rivers is about 97 miles. The average slope of the upper portion is about 2 feet per mile, decreasing to 0.37 feet per mile at the mouth. Navigation has been improved for 90 miles by the construction of three locks and dams.

Fig. 11



(NOTE.—For explanation of figures see p. 1287.)

The upper three-fourths of the basin lies in mountainous territory, and less than one-twelfth of the entire basin is tillable. The total population of the basin is 834,845 (1940). Natural resources in the form of bituminous coal, oil, and natural gas, have attracted a number of chemical plants to the Kanawha Valley and the area is becoming one of the important chemical-producing centers in the country.

The principal tributaries are the New, Gauley, and Elk Rivers. The Elk is highly polluted by oil refineries and gas plants.

Scattered samples taken at Point Pleasant on the Kanawha River (mile 0.6) from August through November 1939 shown an exceptionally low coliform organism count and very low biochemical oxygen demand, indicating that the stream at this point is undoubedly quite clean (table 8). This is confirmed by the absence of class II organisms. The total plankton population is also low, although the sample of August 10 showed very large numbers of *Cryptomonas*, which persisted to a lesser extent in later samples. *Chrysococcus* was relatively scarce.

Samples throughout the month of July at scattered points up the river as far as Montgomery (mile 85) show a somwehat higher plankton volume, with occasional class II organisms appearing. *Cryptomonas* was high for some 30 miles or more up the river during this period. In October, samples from points in the headwaters of the river showed very little plankton, mostly *Cryptomonas*, *Chrysococcus*, and *Chlamydomonas*.

UPPER THIRD

Monongahela River.—The Monongahela River is formed by the junction of the West Fork and Tygart Rivers about 1 mile south of Fairmont, W. Va. It flows through Pennsylvania, uniting with the Allegheny River at Pittsburgh to form the Ohio River. Its length is about 128 miles, and it drains an area of 7,380 square miles. The average slope in the upper part is 2.1 feet per mile, which later drops to about 0.7 feet per mile. Fourteen locks and dams have been constructed along the river.

The Monogahela River is subject to an enormous amount of industrial pollution. A great portion of this pollution is acid waste of one type or another. During the latter part of June 1940, while the water was still fairly high and rains were frequent, the pH of the stream in the 50 mile region between Morgantown (mile 100.9) and Roscoe (mile 48.5) hovered in the vicinity of 6. On either side of this intermediate region, the pH fell off rapidly, being approximately 3.7 at Pittsburgh (mile 0) and at Worthington on West Fork (mile 136). During this period the dissolved oxygen was fairly high. Plankton and chemical samples were available for August 19 from dam 8 at mile 90 down to dam 2 at mile 9 (table 9). At this time the pH of the whole 80 miles lay between 3.3 and 3.7. Coliform organisms were practically absent and the biochemical oxygen demand was about 0.65 parts per million or less. The plankton volume was low and consisted almost exclusively of *Closteriopsis*. A few diatoms were found locally. Plankton samples taken late in June showed many *Navicula*, some *Cymbella*, *Dinobryon*, and some unidentifiable green flagellates in the vicinity of Morgantown.

Fish studies were made during the latter part of June and the first part of July. In the upper region, on the West Fork of the river, at Good

Hope, W. Va., there is a fair fish population, consisting of long-eared sunfish, smallmouthed bass, redhorse suckers and rock bass, together with a rather large number of various shiners and minnows. Only one shiner each was found at Rivesville and Worthington. From there (mile 136) to the mouth of the Monongahela, only an occasional fish (shiner) was collected, except near the mouth of a nonacid tributary. Many of these nonacid tributaries contribute a good mixed fish fauna, but the fish apparently do not become established in the Monongahela. Many catfish, carp, and suckers, as well as some of the game fish, were found dead or dying below the entrances of such tributaries.

No fish, with the exception of one small sunfish and one small catfish, were taken on the Tygart below Grafton Reservoir, although the State had stocked the reservoir with game fishes.

Allegheny River.—The Allegheny River has its source in north-central Pennsylvania. It flows in a northwestern direction into the State of New York, turns and flows back into Pennsylvania. From here its course is southwest to Pittsburgh, where it unites with the Monongahela River to form the Ohio. Its length is about 325 miles. The average slope below Olean, N. Y. (mile 259), is 2.7 feet per mile. The drainage area is about 11,730 square miles, of which 9,775 are in Pennsylvania and 1,955 are in New York. This area lies in the Appalachian Plateau and is, for the most part, hilly or mountainous. The river has been improved for navigation by the construction of 8 locks and dams, to mile 61. The population of the basin (1940) exclusive of the city of Pittsburgh, is approximately 1,237,000. The distribution between urban and rural population, also exclusive of Pittsburgh, is 42 percent and 58 percent, respectively. The population (1940) of Pittsburgh is 671,659, of which slightly over one-third is in the Allegheny River Basin.

In contrast to the Monongahela River, the Allegheny, above mile 50, shows a pH 7 or higher. Below this point a certain amount of acid pollution occurs.

Samples were taken of the main stream during the month of August 1940 (table 10). Following downstream, the Tionesta River (mile 154) seems to be the source of the first heavy pollution. From the chemical data, there would seem to be some acid pollution as well as an introduction of organic material. The dissolved oxygen drop sharply to about 5 parts per million. The reserve alkalinity drops and the pH is about 7.4. These effects may be due to a tannery located on the Tionesta.

There is a plankton population below the Tionesta of about 1.5 parts per million. Diatoms are plentiful and class II organisms are infrequent. From Kennerdale (mile 110) down, the plankton is composed almost entirely of class I organisms, especially diatoms.

The irregularities of the plankton volume figures are accentuated by numbers of the large diatom *Surirella* at miles 14, 50, and 70. It is striking that at Brackenridge (mile 22) no plankton whatever was found. Biochemical oxygen demand values of about 1 part per million in this region of the stream above mile 50 are, in general, higher than in the acid stream below. At Pittsburgh a large number of coliform organisms are introduced into the river with a relatively slight change in the biochemical oxygen demand.

The Allegheny River, from the headwaters to Kittanning (mile 46), supports a fair mixed fish population. Various suckers, crappies, bass,

and sunfish were collected at Warren, Pa. Further down the stream, at East Brady, bass, hogmolly, and quillback suckers were taken. At Mosgrove, suckers, wall-eyed pike, trout perch, and smallmouthed bass were fairly abundant.

The Clarion River supports a large fish population consisting of yellow perch, small- and large-mouthed bass, rock bass, catfish, suckers, carp, and numerous snapping turtles. This stream is colored black from tannery and paper-mill wastes in the headwaters. Fish caught in this stream could not be used as food, as their flesh was tainted from the chemicals. The Tionesta, also polluted by paper and tannery wastes, supports a large fish population. Many of the streams tributary to the Clarion and the Tionesta contain trout, but no trout were taken in the main stream. The Kiskiminitas River is too acid from mine drainage to support fish.

Muskingum River.—The Muskingum River is formed by the confluence of the Walhonding and Tuscarawas Rivers at Coshocton, Ohio. It flows in a southeasterly direction and empties into the Ohio River at Marietta. Its length is about 110 miles and average slope 1.5 feet per mile. The Muskingum drains an area of 8,040 square miles, comprising about 20 percent of the entire State of Ohio. The northern and western portions of the basin have been smoothed by glacial action, and the topography is undulating to rolling. Seventy to eighty percent of the basin is used for agriculture. The rate of flow is controlled by reservoirs in the upper part of the watershed. Eleven locks and dams have been constructed to a distance of 91 miles from the mouth of the river.

The total population of the basin in 1940 was 812,028, about equally distributed between urban and rural inhabitants.

The leading industries are steel, metal products, clay, rubber, and paper. Coal is mined to a limited extent in the eastern part of the basin.

The data for the Muskingum River are particularly unsatisfactory, as this watershed was subjected to rains during most of the period of study. As a result, plankton samples are scattered in date between the beginning of April and the end of August 1940. It is unfortunate that the one good series of plankton samples taken on July 19 is unaccompanied by any chemical data. The April samples show diatoms almost exclusivesy, although the plankton volume is low. These conditions still exist at the mouth of the river early in June. Below Zanesville (mile 75) at this time there is a considerable volume of plankton containing an occasional *Euglena* or Protozoan but still composed, to a large extent, of diatoms. In July the plankton was somewhat more varied, while in August a sample taken above McConnelsville (mile 48) at Duncan Falls (mile 66.8) showed the plankton well distributed among the different taxonomic groups.

The series of July 19 was taken from Zanesville to below Stockport (mile 39) and indicates the following influences (table 11). The plankton volume is quite high in the region below Zanesville, dropping somewhat as one approaches Duncan Falls. At Duncan Falls the volume again increases sharply, with an increase in the number of class II organisms. From Duncan Falls through Gayport and McConnelsville, the volume drops off somewhat, although still maintaining high levels, and a further drop occurs below Stockport. The plateau between Gayport and McConnelsville may be due to an

absence of intermediate samples. The watershed supports a good mixed fish population.

Hocking River.—The Hocking River, having its source about 35 miles southeast of Columbus, Ohio, empties into the Ohio River at Hockingport, Ohio. Its length is about 100 miles. The average slope above Lancaster (mile 89) is 4.5 feet per mile, and the lower part of this river has a slope of 2.3 feet per mile.

The Hocking River drains an area comprising 1,185 square miles. The population of the basin in 1940 was 113,555. A little more than half the population is urban. The natural resources of this area are coal, clay, natural gas and oil, and farming is the principal industry.

Scattered samples were taken at various points on the Hocking River in late May, June, July, and August, 1940. In May, samples taken at Coolville (mile 5) and Guysville (mile 20) showed a plankton largely composed of diatoms, with some *Cryptomonas*, *Chrysococcus*, *Dinobryon*, and an occasional ciliate or *Euglena*. The most abundant organism was *Navicula*, a diatom. The plankton at Coolville was rather more abundant than at Guysville.

A sample taken below Athens (mile 35) in late June showed a varied plankton population with considerable numbers of class II organisms. The plankton at Hockingport (mile 0.1) at the same period was somewhat less abundant and contained fewer class II organisms and more class I forms. In July the plankton of the lower river was quite abundant and varied. There were considerable numbers of class II as well as class I organisms at Hockingport, Coolville, and Guysville. There was little plankton at Nelsonville (mile 53), while the plankton above Logan (mile 67) consisted mainly of diatoms, with some *Euglena*. Below Sunday Creek (mile 42) the plankton was much reduced, both in kind and number. The most common forms were the diatom, *Asterionella*, and *Oscillatoria*, a blue-green alga

In August a fairly complete series was obtained from below Nelsonville to Hockingport (table 12). The dissolved oxygen during this period was fairly good, with a depression in the values below Athens. The plankton was fairly abundant below Nelsonville, being composed largely of class II organisms. Between Nelsonville and the region above Athens the plankton volume was sharply decreased. This was undoubtedly due to the influence of Sunday and Monday Creeks, which were pouring water of approximately pH 3 into the main river. A resurgence of the plankton occurs from Athens to Guysville. The depression at Coolville cannot be well explained except as indicating the absence of an immediate source of pollution. At Hockingport the plankton volume was again high, passing 6,000 parts per million.

Fish collections made during this August trip showed that smallmouth bass were plentiful below Nelsonville and that biological conditions in general seemed good. Hogmolly and shiners of all sizes were present, crayfish were plentiful, and there were many empty mussel shells. However, there was a whitish growth noticeable on the bottom and on the rocks. Above Athens, below the entrance of Sunday and Monday Creeks, fish were less plentiful. Minnows were numerous, but bass were found in much smaller numbers and hogmollies were replaced by quillback suckers. The bottom of the stream was of a greenish-black color.

At Coolville fish seemed quite abundant. Many people were fishing on and alongside the dam. The seine caught numerous small catfish,

common and quill back suckers, smallmouth bass, and hogmollies. In general, these fish were larger than those caught upstream.

Little Kanawha River.—The Little Kanawha River rises in the western foothills of the Allegheny Mountains, near the eastern border of West Virginia, and flows north about 160 miles, emptying into the Ohio River at Parkersburg, W. Va. The average slope below Burnsville (mile 122) is about 1.5 feet per mile. The river drains an area of 2,320 square miles.

The basin has been cleared of forests, except above Burnsville, and is devoted to agriculture. Oil and gas fields are located over a considerable portion of this area. There are also local coal deposits in the region of the headwaters. With the exception of oil and gas, there is little industrial development in this basin. The population in 1940 was 92,355, almost entirely rural.

A series of samples was taken along the Little Kanawha River from Glenville (mile 103) to its mouth, late in August, 1940 (table 13). The plankton at lock 3 (mile 25) and above is rather low for the most part. The high volumes appearing in the table at miles 28, 80, 101, and 103, are each due to one or two specimens of large diatoms which affect the volume figures considerably.

Creston (mile 48) and Elizabeth (mile 27) seem to be the principal sources of pollution along the upper stream. Below Elizabeth the Hughes River enters at mile 17 and carries only a small volume of plankton. The upper Little Kanawha River has the local reputation of being the best bass water in the State. The stream, at the time of investigation, was low and the volume of water small. Seining conditions on the whole were bad. Net catches consisted mainly of common and redhorse suckers, turtles, and an occasional Kentucky bass. At Creston, where the West Fork enters, fish were relatively plentiful, suckers of various kinds and a few smallmouth bass being noted. The West Fork has a reputation as a good pike stream, having some deep holes from which large fish are occasionally caught. Below Elizabeth, catches consisted of small suckers, sheepshead, mooneyes, crappies, and white bass. Seining conditions were unfavorable.

At the time of our visit in August, peculiar conditions were found at the mouth of the river from dam 1 (mile 4) to the Ohio. The The water was highly turbid and opaque, and there was considerable scum on top. The water coming from the pool above made a distinctly marked area of cleaner water below the dam. In this region fish were actively breaking water, while further below the scum was unbroken. At the East Parkersburg Bridge, the same general conditions prevailed, except that no fish were seen. Dissolved oxygen determinations showed 0.33 parts per million of oxygen at the bridge. Immediately above the dam the oxygen value was 5.9 parts per million, while at the lower end of the lock wall, in the scum-covered region, the oxygen was 3.3 parts per million. There were, furthermore, distinct temperature and pH differences between the water above and below the dam, the pH being lower and the temperature being higher below the dam.

The plankton on this date showed a large bloom of *Pandorina* above the dam and extending into the pool below. The numbers of *Pandorina* at the East Bridge were considerably lower, although still high. These organisms formed the bulk of the plankton population.

According to observers, fish had been dying in the pool for several weeks. Evidence of this was found below the dam, where numbers of dead fish were floating and stranded on the shore. These included bass, suckers, mooneyes, shiners, sunfish, crappies, some very large pike, and other large fish no longer indentifiable, as well as salamanders and other water creatures, but notably few catfish were found. According to the lockmaster, this fish slaughter has occurred every year under similar weather and low-water conditions. In years when a temporary rise occurred in the middle of the season, there would be a recurrence of fish deaths as the water again subsided. Under these lethal conditions the water becomes unfit even for industrial use by the large viscose plant located at Parkersburg. This plant has an accessory water intake above the dam for use during these periods.

As stated above, very few catfish were found among the material stranded on the bank. However, on August 23, at the East Bridge, it was noted that large numbers of black catfish were seen along the surface of the river, moving very little but occasionally struggling or disappearing temporarily from the surface of the water. It proved possible to catch some of the fish from the shore by means of a dip net. The fish would swim slowly along the surface and go directly into the net without any effort to escape. An occasional very small fish, other than catfish, was seen along the shore, which was apparently able to survive the water conditions temporarily. Measurements showed that there was zero oxygen concentration in the water at that point.

Measurements in the vicinity of the dam showed that the oxygen values had fallen at this point also, being approximately 4.7 parts per million above the dam and 2.3 parts per million below the dam. The temperature and pH differences between the two sides of the dam still existed. The plankton distribution had changed overnight. The number of *Pandorina* above the dam had dropped, while below the dam it had risen appreciably. This seemed to indicate that there had been a wave of these organisms which had passed over the dam.

Pandorina "blooms" have been found at other times and places and, in general, the evidence is that these blooms raise rather than lower the dissolved oxygen. In no case have they been found toxic to aquatic life. It is, therefore, clear that the conditions at Parkersburg cannot be blamed on this organism. In view of the circumstances and the general condition of the river at this point, it seems clear that some relation exists between the low dissolved oxygen values, which presumably have been causing fish deaths, and local industrial plant operations. The details of this must, of course, be investigated in order to determine exactly what is responsible for this slaughter. The most likely presumption is that some carbohydrate industrial effluent, under high temperature and low water conditions, furnishes the substrate for heavy bacterial growth with the resultant exhaustion of the oxygen supply.

LOWER THIRD

Wabash River.—The Wabash River rises in Mercer County, Ohio, and flows across Indiana to Covington, before turning south to join the Ohio River about 10 miles above Shawneetown, Ill. This basin covers most of the State of Indiana and a large section of Illinois. The total area of the basin is 33,100 square miles, 320 square miles, or 1 percent, of which is in Ohio; 24,220 square miles, or 73 percent, in Indiana; and

8,560 square miles, or 26 percent, in Illinois. Included in this area are the tributary basins of the White River, the Embarrass River, the Vermilion and Little Vermilion Rivers, the Little Wabash, Eel, Mississinewa, Patoka, and Tippecanoe Rivers. The length of the Wabash River is about 475 miles. The average slope below Lafayette (mile 311.7) is about 0.6 feet per mile.

The population of the basin in 1940 was 2,508,598, divided about equally between rural and urban dwellers. Indianapolis, situated on the White River, with a population of 386,972, is the largest city in the basin.

The leading industries are manufacture of steel, paper, textiles, leather, machinery and transportation equipment. A small amount of coal is strip mined in the western part of the basin. A large portion of the building limestone of the country is produced around Bloomington. Oil production in eastern Illinois, near New Harmony, Ind., is increasing.

The plankton samples for the Wabash River were taken during August, September, and October 1940, with the majority of the samples taken in September. Rain occurred in the Indiana region at the end of August, and September 10 and 25. The September rains were generally light and did not appreciably affect stream conditions, except for the samples taken during the rain. Because of the time spread of the samples, it is not possible to present the results of this study in a single continuous curve. It will be necessary, therefore, to discuss the findings with some regard to the time sequence.

One of the characteristic organisms of the Wabash River and also of the White River, is a *Stephanodiscus*, which appears frequently and in large numbers. The combination of size and number exerts a great effect upon the plankton volume figures. In August this organism was found localized in the upper portion of the river, above Logansport (mile 355). Later in the month numbers were also found at Pittsburg (mile 331) and Hillsdale (mile 238). Rains occurred throughout the watershed the last days of August and may have been instrumental in the new distribution found in the first few days of September. At this latter time the diatom was almost totally absent above Logansport, but was found in numbers from Logansport to the vicinity of Lafayette. Toward the end of September and early in October, its population center above Logansport was again established, though the organism could also be found at Georgetown (mile 347).

In addition to this factor in the volume values, there must be noted the usual seasonal fluctuations of the relative numbers and distribution of the plankton (table 14). It should be borne in mind that the Wabash River has no dams to cause a pooled condition of the river during the summer low-water period. The flow is, therefore, somewhat swifter than in a dammed stream. In general, as the summer season advances and the river level drops, it will be found that the plankton volume drops and the proportion of class II organisms increases immedialely below the source of pollution. Examples of this are found in the region below Terre Haute, Perrysville, Logansport, Peru, and other major points of pollution. This may be ascribed to the sequence of the processes of decomposition of organic pollutants outlined above.

Conversely, at points further downstream, below these same sources of pollution, the proportion of class II organisms may decrease, due to

the upstream completion of the disintegration process under higher temperatures and reduced stream flows.

At the end of September, and the beginning of October, when low temperatures start to appear in this basin, the plankton is found to decrease sharply and the class II organisms and certain of the intermediate group become diminished in number, or are totally absent. This parallels the findings in other basins.

Judged by the plankton volumes, certain of the towns along the upper river are important sources of pollution. This is readily checked by casual visual survey of the regions involved. Peru, for example, for a short distance below the outlet of its sewage treatment plant, produces a heavy algal growth along the river, which in this region is rather shallow. This characteristic of the river bed becomes further accentuated nearer Logansport. Above Logansport the stream appears rather clean. Commencing at the outfall of the upper sewers, there is found a region of intense pollution, which exists downstream for a considerable distance. During the summer season the stream at this point is shallow and rocky, so that considerable pooling results and numerous narrow channels are formed. The bottoms and sides of the channels are covered with a growth of attached *Protozoa* and other organisms common to extremely polluted regions. Farther downstream the growth of algae is very heavy and the various odors are unmistakable. It is probable that under conditions of high stream flow the sewage introduced at this point is carried for a considerable distance downstream.

The peak of the plankton, due to Logansport pollution probably, occurs in the region of Delphi, some twenty-odd miles downstream. From Delphi the volume of organisms drops off until the influence of the Lafayette effluent is felt in the vicinity of Independence (mile 294). At times of high water the peak may occur farther downstream.

Terre Haute (mile 215) is a source of heavy pollution to the Wabash River. In addition to the untreated domestic waste of its residents, a number of commercial plants along the stream introduce their wastes into the river. At this point the current is fairly swift so that the waste materials are distributed for a considerable distance downstream. Nevertheless, the combination of sewage and industrial wastes introduced at this point results in a dissolved oxygen of less than 4 parts per million and high coliform organism and biochemical oxygen demand values for some 35 miles downstream. Due to the swift current and distribution of the pollution over a considerable length of the river, the fertilization effect on the plankton is not localized to the point of producing a prominent peak such as is found under certain other conditions. Such peak as there is seems to occur far downstream at Meron Ferry (mile 165). Both magnitude and location of the peak are variable.

From Meron Ferry dowstream the plankton volume gradually falls off. There is a slight peak at Patton (mile 102), and from a point below Mount Carmel (mile 95, below the mouths of the White and Patoka Rivers) there is a slight rise in the plankton volume as the mouth of the river is approached. This may be due to a combination of additional pollution from towns along the river and the influence of the dams on the Ohio River in slowing up the flow at the mouth of the Wabash. This allows time for the organic material to decompose to available food and for the plankton organisms to multiply.

The Wabash River on the whole has a good fish fauna. Certain of its tributaries have the reputation of being excellent game fish streams. Among these may be included the Mississinewa, Tippecanoe and Eel Rivers. Wildcat Creek, which enters above Delphi, is also rich in game fish. Above Peru, the Wabash River contained smallmouth bass, crappies, sunfish, mooneyes, and shiners. The crayfish found in this location were clean and brightly colored, similar to those in the Mississinewa River, which enters close by. Below the Peru sewage plant, where the water supported a heavy growth of algae, gar pike, common suckers, several smallmouth bass, smallmouth buffalo, mooneyes, sunfish and shiners were present. Above Logansport, in addition to gar pike, common suckers and smallmouth bass, a number of channel catfish were present. Sunfish and shiners were also abundant. Large fish were seen breaking water farther out in the stream. Many snails were present in this region.

Below Logansport, in obviously foul water with heavy sludge and marginal algal growth, fish were relatively scarce; several suckers, sunfish and shiners constituted the catch. At Delphi, fish were plentiful and varied. Smallmouth and white bass were caught, and common and redhorse suckers were large. Mooneyes were also of large size, both yellow and channel catfish were found, and long-eared sunfish, shiners and darters all seemed well fed.

Above Lafayette, smallmouth bass seemed common, while sunfish, shiners and darters were quite plentiful, in spite of poor seining conditions. Below Lafayette, bass were absent but gar pike, channel catfish, mudcats, shiners, darters and sunfish were plentiful. The marginal algae were very abundant. The river bottom consisted of shifting sand. At Covington, the fish species again became numerous, and varied. White bass and large- and smallmouth bass were present, as well as mudcats and bullheads, quillback suckers, sunfish, shiners and gar pike. The bottom of the river was muddy in this region.

At Montezuma several white bass were taken, while both mud and channel catfish were very numerous, but small. Sunfish and minnows were plentiful, and quillback suckers were also caught. Natives report buffalo and suckers present. A short distance above Terre Haute the seine captured largemouth bass, common suckers, channel catfish, mooneyes and shiners. Quillback suckers were extremely numerous at this point. White bass were reported to be present.

In contrast to upstream conditions, below Terre Haute, where the stream was narrow and swift, with a clean, rocky bottom, no fish at all were taken and only two sick crayfish were found. The water was noticeably bad; garbage, algae, paper, fiber mill wastes and other debris could be seen floating in the stream.

Ten miles below Terre Haute natives reported fish to be absent; confirmatory seining was not attempted. The dissolved oxygen at this point was still below 4 parts per million. At Meron Ferry, quillback suckers were very numerous, with sunfish, mooneyes and shiners also present. A recently dead sturgeon was found floating, and the remains of buffalo and crappies were found on the shore. Local fishermen were seen with catches of black bullheads. The natives report that bass were once plentiful at this point but are now absent.

Below Vincennes, sunfish and shiners were very abundant with an occasional small mudcat and darter. At this point there was considerable growth of algae along the shore and on the bottom of the

stream. At St. Francisville, numbers of quillback suckers, shiners, chubs and some mooneyes were again collected. There was a very noticeable tendency on the part of the quillback suckers to restrict themselves to that portion of the bottom covered with algae and to be almost totally absent from the uncovered area.

Below Mount Carmel and the mouths of the tributaries at that point, fish were varied. Large- and small-mouth black bass, sunfish, channel and mud catfish, quillback suckers, and shiners were caught, as well as gar pike. Live mussels were seen, but there were no crayfish. The bottom was sandy.

At Grayville, Ill., (mile 61), large-mouth (Kentucky?) bass were plentiful, and white bass were extremely numerous. Shiners, sheepshead, quillback suckers, mooneyes, gar pike and channel catfish were found. Commercial fishermen showed large buffalo and quillback suckers, channel cats, and eels. They claimed that carp and other types of fish were also present. Below New Harmony, channel catfish, largemouth bass, and white bass were noted, but the principal fish present were sheepshead, quillback suckers and shiners.

Upper tributaries: The Mississinewa River, which enters the Wabash 375 miles above its mouth and a short distance above Peru, was quite clean and contained less than 0.5 thousand parts per million plankton. The Eel River enters the Wabash 354 miles above its mouth, at Logansport. This is considered to be a clean stream and is used for the town water supply. At the sampling point near the intake of the city water supply, over 11 thousand parts per million of plankton were found, consisting mainly of the diatom, *Stephanodiscus*. However, there were close to 0.2 thousand parts per million of class II organisms. Observations seemed to indicate that this was a favorite spot for horse washing, as these animals were led into the stream and cleaned at this spot.

Wildcat Creek, entering the Wabash River at mile 317 near Delphi, contained over 2.5 thousand parts per million of plankton, principally intermediate forms. Many small- and large-mouth bass were found here. Common, quillback and hogmolly suckers were caught. Sunfish, crappies, bluegills, mudcats, shiners, and darters were plentiful. Large gar pike and walleyed pike were reported present by local residents.

Tippecanoe River (mile 322): The water of the Tippecanoe River is very clear. The river itself has a larger bottom growth of the higher aquatic plants than was usual in the Wabash watershed. Samples were taken in the river, and the two lakes which form a part of it, about September 7. Plankton was found to be less than 0.7 thousand parts per million at all stations, although ten days earlier it had been as high as 5 thousand parts per million at one of the lakes and 1.8 thousand parts per million at the lowest sampling point. A certain number of class II organisms were present in the upper reaches of the river and in the lakes. At Springboro, above the mouth of the stream, these were absent, although a few filaments of *Sphaerotilus* were found. The number of class I organisms was somewhat higher at this point.

At Springboro a number of small-mouth bass, hogmollies, shiners, and darters were found. Larger specimens of these species, as well as common suckers, could be observed in the clear water from the bridge over the stream. The river is apparently a popular fishing stream and the lakes are widely used as summer resorts.

Vermilion River (mile 257): The Vermilion River was studied in the region of Danville, Ill., not far above its mouth. Above Danville stream conditions were fairly good. The dissolved oxygen was approximately 9 parts per million and the total plankton less than 1.5 thousand parts per million.

Following the stream through the town reveals a drop in dissolved oxygen and an increase in the algal growth. Below town, about 100 yards above the entrance of the sewage plant effluent, the dissolved oxygen was 3.5 parts per million and a few sunfish, minnows and small black bass were noted. These were not in prime condition. Floating masses of blue-green algae were seen and the total plankton volume was about 5 thousand parts per million, of which about 3.25 thousand parts per million consisted of class II organisms.

About 1 mile below the sewage plant the disolved oxygen was 1.87 to 2.05 thousand parts per million, and the total plankton varied between 6.5 and 9 thousand parts per million on successive days. Class II organisms composed over two-thirds of the plankton. The water was obviously polluted and there was considerable sludge on the bottom. Several sunfish and two small German carp were caught, even though the dissolved oxygen value was below 2 parts per million. About 5 miles downstream, conditions improved somewhat, the dissolved oxygen rising to about 5.5 parts per million. Fish were numerous. Many largemouth bass, a small number of smallmouth bass, sunfish, yellow catfish, spotted darters, log-perch, quillback, and common suckers, shiners, and carp were caught. However, a large number of the fish were sickly, abnormal, or parasitized. The bottom was still noticeably muddy. The total plankton had dropped to 3 thousand parts per million at this point and the volume of class II organisms was about 0.5 thousand parts per million.

At the time of sampling, the plant effluent was approximately one twenty-eighth of the total stream flow.

The Embarrass River (mile 122): The Embarrass River, above Lawrenceville, Ill., in the middle of September, 1940, had a plankton population of 5.9 thousand parts per million, due to a large number of the diatom, *Pleurosigma*. Some class II organisms were present. Two weeks earlier the *Pleurosigma* and class II organisms were both much more abundant. Several miles below Lawrenceville, at Billet, the volume of class II organisms increased to 0.8 thousand parts per million and the total plankton was 0.9 thousand parts per million. Above Lawrenceville, largemouth bass were extremely numerous and many quillback suckers were caught. There were some minnows, long-eared sunfish and gar pike. A carp weighing 7.5 pounds was also caught. The stream was not very wide at this point, but there were apparently some deep holes. Dissolved oxygen was 8.7 parts per million. At the sampling point below Lawrenceville, oxygen was close to 9 parts per million, but no fish or crayfish of any kind could be found. There was a scum of oil covering a portion of the water, and algae were floating and on the bottom. The bottom itself was an oily mud. No insects could be seen, and the water was fairly clear.

Little Wabash River (mile 15): The rate of flow was very low in the Little Wabash River (late September). At Carmi, Ill., the water was quite stagnant, with a heavy growth of algae covering the surface. The dissolved oxygen was high and approximated 12 parts per million. The plankton found consisted mostly of class I organisms.

Below Emma, Ill., deep, quiet pools occur, in which the water was quite stagnant and green. Fish were occasionally seen to break water. The plankton here was approximately 6 thousand parts per million, with over 20 percent of this being composed of class II organisms.

White River (mile 96): The majority of samples from the White River were taken in the latter half of September. Three or four samples were taken in the third week of August. Samples from a given region were taken at the same period so that consecutive points in the region of a source of pollution are comparable.

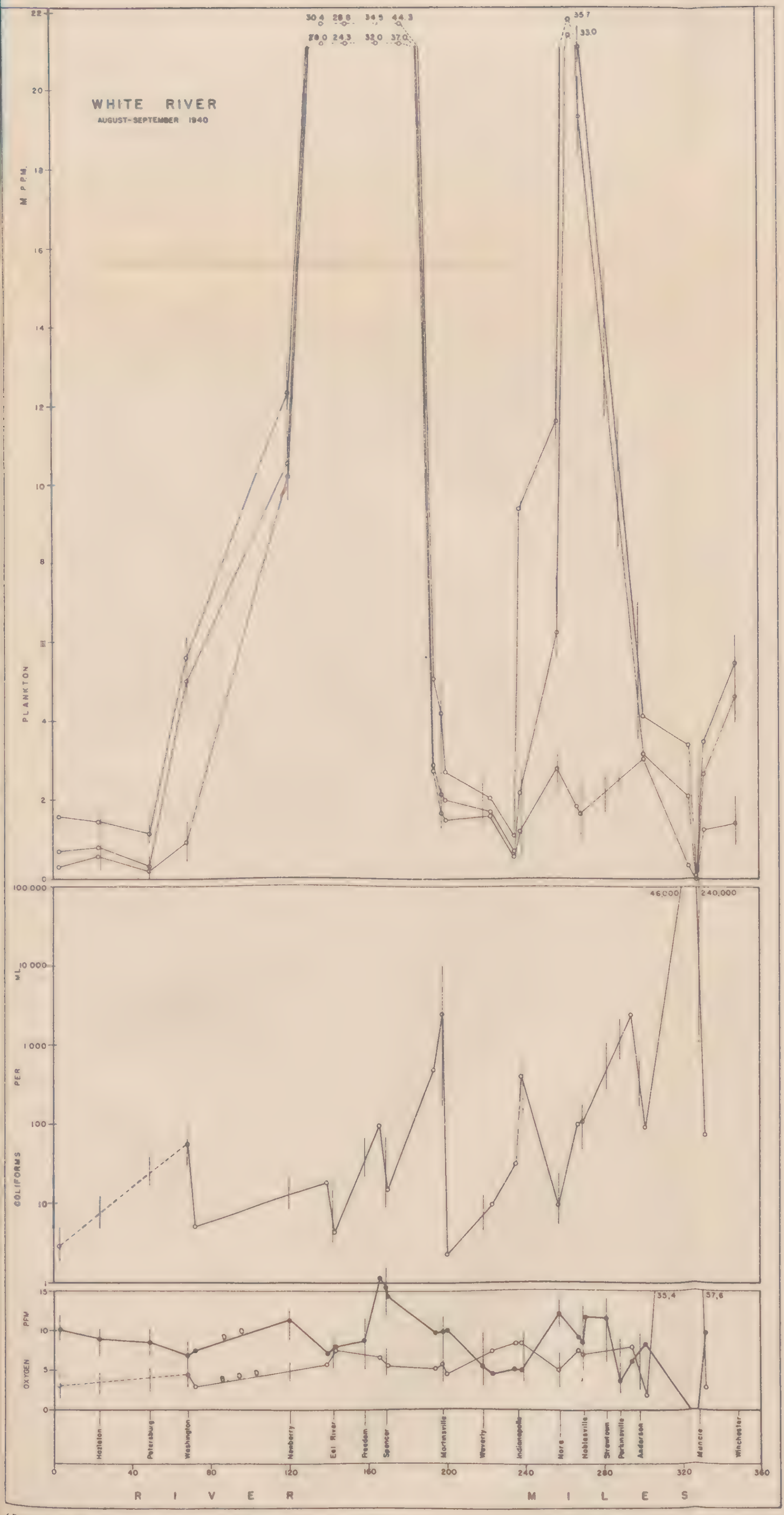
As the studies of other rivers have shown, the month of September is one of stable conditions, during which light rains exert little, if any influence upon the stream plankton. For this reason and because of the general agreement between the values at different points, figure 12 may be taken as representative of the September conditions on this stream.

The White River is subject to heavy pollution for almost its entire course (table 14). Our observations started at Winchester (mile 338) and Muncie (mile 309) where samples were taken in August. The pollution immediately below Muncie, as indicated by the biochemical oxygen demand and coliform organism values, is so intense that the plankton population is almost entirely destroyed. It is possible that some ciliates exist under these conditions, that for various reasons, did not show up in the plankton samples. The recovery below Muncie is rapid but the plankton volume reaches its peak in the region above Noblesville (mile 265), where a tremendous growth of class II organisms was found. A large part of this growth consisted of *Euglena*, but *Vorticella* and other forms contributed a considerable volume. Anderson (mile 297) undoubtedly contributed a portion of the pollution responsible for this burst of plankton, but it seems possible that the height of the peak is related to the heavy organic load introduced at Muncie. The plankton volume fell below Noblesville, and by the time Nora was reached, a few miles above the city of Indianapolis, the total volume, and especially that of the class II organisms, had decreased greatly. In passing through the city of Indianapolis, the plankton concentration of the White River was severely reduced. This may partly be due to the number of tributaries which enter the White River in this region, to the large portion of the water which passes through the city waterworks during low water, and possibly to specific pollution factors.

The plankton recovers slowly below Indianapolis. This continues until Martinsville is reached. Below Martinsville (mile 194), conditions seem to be favorable for the proliferation in great numbers of large species of diatoms, especially *Stephanodiscus* and *Synedra*. This diatom population continues on past the mouth of the Eel River to Newberry, where, possibly due to the diluting effect of this tributary, the total volume falls off. At Washington (mile 62) most of the *Stephanodiscus* have vanished and class II organisms appear under the influence of fresh pollution at this location. From this point downstream the total volume of plankton falls off to approximately 1.5 thousand parts per million above the mouth.

At Perkinsville, several miles below Anderson, bass, buffalo, shiners and a black bullhead were caught. The water was obviously dirty at this point, with algae covering the stream botton. At Strawtown,

FIG. 12



(NOTE.—For explanation of figures see p. 1287.)

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several miles below, the appearance of the stream was much better, pollution not being obvious. At Noblesville many shiners, some sunfish, and some darters comprised the catch. Stream conditions appeared good. Local fishermen reported that bass, buffalo, carp, catfish, crappies, bluegills, and other fish are caught in season.

At Nora, smallmouth bass and some shiners were caught under difficult seining conditions. Some large unidentified fish escaped. It is assumed that under better seining conditions the catch would have been considerably greater.

Below Indianapolis, above the last waste outfall, some sunfish and a largemouth buffalo were caught. The bottom was gravel, with a strong current, but considerable blue-green algae were visible. Fishermen reported that only carp and catfish were caught here. Fish, presumably mooneyes, were seen breaking water occasionally at the mouth of the outfall. A local resident told of many fish deaths a distance above the sampling point a week or two earlier. The period of the slaughter coincides with that of the hottest weather of the month The above story is borne out by the extremely numerous skeletons and weathered corpses of large fish along the shore.

At Martinsville large common and quillback suckers, hogmollies, sunfish, and numerous minnows are found. One largemouth black bass was caught. The river bottom consisted of black oily mud with a strong odor, and algal growth was plentiful. All the fish caught showed a tendency to the dark phase, which in the minnows was expressed so strongly that the dorsal color was bluish-black.

At Spencer the bottom was muddy but had a sandy underlayer. There was a green covering on the flat rocks in the stream. Common and quillback suckers, spotted suckers, sunfish, channel catfish, shiners, and chubs were caught and largemouth bass were very plentiful. It is possible that the fish were more active due to the rain which fell the previous night and the early part of the day.

At Newberry largemouth bass were caught, as were some sunfish, shiners, and darters. Channel catfish were numerous. There was no mud on the bottom, possibly due to the marked current, but algae were visible.

The Eel River, whose mouth lies above this point (plankton 0.6 thousand parts per million, dissolved oxygen 8.5 parts per million), had a number of largemouth bass, possibly some Kentucky bass and shiners, darters, and some minnows. Below the sewer at Washington, the bottom was sandy but there was a slight odor to the water. Seining conditions were not good. Gar pike, largemouth black bass, quillback suckers, and shiners were caught, while channel catfish and darter were also plentiful. Above Petersburg, the White River is joined by its East Fork, which appears to be a good stream (plankton 0.5 thousand parts per million, dissolved oxygen 7.75 parts per million. Conditions here were not very favorable for seining, but largemouth bass, channel catfish, quillback suckers, shiners, and sunfish were caught. Blue herring were found in large numbers at this point. Below Petersburg considerable mud was encountered in the White River. Channel catfish were plentiful, with mudcat also present. Small bass were numerous, many quillback suckers were found, and sheepshead, shiners, sunfish, and several types of minnows were caught.

Below Hazleton, stream conditions looked good. Several largemouth bass and some gar pike were caught, sheepshead, mooneyes,

quillback suckers, and shiners were plentiful. No catfish were obtained, even after extensive seining. The bottom was sandy.

Above the mouth of the White River, largemouth black bass, small mudcat, sunfish, and minnows were caught under unfavorable conditions. Buffalo, carp, and gars were reported to be plentiful, bass less numerous, and it was said that an occasional sturgeon was caught. This information was derived from the proprietor of a local fishing camp. Some large, slimy fish (gar or sturgeon) tore a hole through the net and escaped.

Patoka River (mile 95): The Patoka River was visited during the middle of September. The first samples were taken a short distance above the mouth. When first observed from the bridge, the water presented a greenish-blue appearance, due to some milky suspended material. Otherwise the water was very clear.

Several large carp and redhorse suckers were seen traveling downstream, while black catfish, a ten-inch bass, an eel, and other large fish were seen moving slowly in various directions. No minnows were observed. The fish were making efforts to escape from the pool in which they were found, but were apparently unable to cross the shallows at either end. The fish were relatively sluggish and it was possible to capture a 23-inch dogfish (Amia calva) in a dip net. Although the condition of the water was attributed locally to the waterworks at Princeton, the waterworks records showed that the stream often was very acid due to mine drainage and pumpage. In addition, there was often a heavy salt load from oil-well pollution, as well as high "hardness" values. A wave of acid water had passed downstream at about the time observations were made. One week later, the pH at the waterworks dam was 6.8. No fish could be found by seining. Plankton was 0.33 thousand parts per million above the dam and 2.5 thousand parts per million below. The waterworks operator reported that sludge was flushed into the stream at intervals of 6 months or longer. No records were obtained of the effects of this sludge upon the aquatic life of the stream.

Saline River.—In early October the Saline River, a minor Ohio River tributary in Illinois, was extremely low and discontinuous, with almost no current. Some regions resembled stagnant sewers. Near the mouth the stream is situated in the Shawnee National Forest. At flood season this locality is a deep backwater of the Ohio River. The bottom consists largely of rock ridges, with deep pools between riffles.

Seining conditions were poor, but largemouth bass, logperch, crappies, and small sunfish were caught. Minnows were seen in the shallows, and larger fish were breaking water in the middle of the stream. A ranger reported a considerable variety of fish, such as catfish, sheepshead, gar pike, etc. Plankton was plentiful, approaching 1.5 thousand parts per million (table 15).

Tradewater River.—The Tradewater River is a narrow, deep Kentucky stream. At the time of observations in October, practically no water was flowing. Fish caught near Sturgis, Ky., consisted of common suckers, Kentucky bass, bluegills, sunfish, quillback suckers, sheepshead, and some shiners. The water appeared green and dirty, but the total plankton volume was only 0.17 thousand parts per million, almost half of this consisting of class II organisms (table 15).

Another sample taken near Providence, Ky., showed crappies, quillback suckers, mooneyes, and some small sunfish and shiners. The water here was shallow and dirty and was used as a watering place for livestock. It is probable that this portion of the river was not connected with the lower river at this season.

Green River.—The Green River rises in Casey County, Ky., and flows in a general westerly direction to join the Ohio River above Evansville, Ind. The length is 370 miles and the average slope below Mammoth Cave (mile 198) is about 0.5 feet per mile. It drains an area of 9,220 square miles.

The population of the Green River Basin in 1940 was 440,000, of which only about 10 percent were found in incorporated towns, the largest of which was Bowling Green (population 14,585). The principal resources are coal, timber, asphalt, oil, and gas. The principal industry is agriculture. Six locks and dams produce slack water up to Mammoth Cave, and one lock and dam each on the Barren and Rough Rivers produce slack water as far as Bowling Green and Hartford, respectively.

The Green River, for a large part of its course, is a wide deep stream and it was, therefore, difficult to estimate the fish population. The trap net was used on a number of occasions and at times it was possible to seine immediately below the dams. Even at these locations, however, conditions were usually unfavorable for fishing. Bait fishermen, however, were successful at a number of locations. Fishing conditions were better in the numerous tributaries of the Green River, and results from these must be used to a large extent.

Plankton, on the whole, is extremely low all along the Green River. For the most part, the total volume is less than 0.2 thousand parts per million (table 15), although a sample taken at dam 4 showed over 1 thousand parts per million. It should be pointed out that this dam lies below the mouth of the Barren River on which is situated the city of Bowling Green. Seining was possible at points from dam 6 at Brownsville up to about Eunice, Ky. In this region could be found smallmouth and Kentucky bass, common, redhorse and hogmolly suckers, log perch, darters, shiners, and an occasional blue herring. Bass caught at Brownsville were a very translucent, pale color and may have been sick. At Munfordville, which is just within the limestone-cave area, fishermen reported catches of large bass, pike, and muskellunge. It is to be noted that the reserve alkalinity in this region of the stream (Munfordville to Brownsville and below) is approximately double that found higher up the stream. This is, of course, to be ascribed to the limestone drainage.

Trap-net fishing between Brownsville and the mouth of the river was on the whole unsucessful, due to the nature of the stream. Kentucky bass and sunfish constituted the catch. Mooneyes were often observed breaking water. Fishermen at dams 3 and 4 had catches of bass and walleyed pike. At Livermore, at the mouth of the Rough River, natives report catfish as the exclusive catch. It was possible to seine the Green River at Rumsey. Bass, sunfish, channel catfish, and shiners were collected. In addition to bass and minnows, blue herring were found at Spottsville, near the mouth of the river.

The tributaries of the Green River showed, on the whole, higher plankton and better fishing than the main stream. However, at this time (October), these streams were very low.

Pond River, into which the sewage of Madisonville is emptied, gave the only catches of small pike; sunfish, bullheads, and shiners were also present. In addition to the Madisonville pollution, there were local pollutions at some of the sampling points, due to their use as water-holes and as pools for domestic fowl. At the mouth of the Pond River, largemouth black bass and Kentucky bass, possibly coming from the Green River, were captured. Natives report fishing in the Pond River to be basically good, but frequent pollution by mine waters kills the fish. Plankton in the stream was uniformly high, approximating 1 thousand parts per million. Near the mouth, the Pond River receives the drainage of Cypress Creek, which is highly polluted by mine wastes. At the time of sampling the pH was 3.2. Plankton was 0. 26 thousand parts per million, almost half of which consisted of the diatom *Navicula*.

The Rough River for the most part showed low plankton and a scarcity of fish. At Falls of Rough, where the plankton was 0.3 thousand parts per million and considerably higher than that found at other poiuts in the stream, sunfish were fairly plentiful, as were shiners and chubs. At Hartford, approximately 20 miles from the mouth of the river, fish were very scarce. Two pavement-toothed redhorse suckers and two shiners constituted the total catch. Acid mine drainage is a source of pollution. The higher points on the stream yielded hogmollies, darters, chubs and shiners.

The Nolin River is, for most of its course, a small stream, along which are situated several towns. At several points plankton is higher than in the Green River. Catches did not contain large numbers of fish, but among them were smallmouth bass, darters, sculpin, sunfish and shiners. The Nolin River runs through the limestone area and enters the Green River near Mammoth Cave.

The Barren River has a navigation dam below Bowling Green, but above that city it is a fairly small stream. The upper reaches consist of alternating shallow, narrow riffles, and large, deep pools. Fishing conditions were not good. Plankton above Bowling Green was less than 0.1 thousand parts per million, although it was somewhat higher in the region of the dam. Shiners, darters, hogmolly and common suckers and sunfish constituted the fish catch in the upper portions of the stream. Natives report a few bass present, especially in the spring. Below Bowling Green and dam 1, log-perch, darters, bluegills, sunfish, common and redhouse suckers, and many small mooneyes were caught. Shiners were seen in the water. Pike and bass fishing were normally good, but at the time of our visit, dynamiting and construction work which was going on nearby probably disturbed the fish.

The Mud River was sampled near its mouth, and yeilded common and quillback suckers,crappies, sunfish, shiners, darters, and some unknown striped minnows. At this point the stream was narrow and deep with a mud and humus botton. At Lewisburg, the oxygen was 2.6 parts per million. The water was black and many dead leaves were present. One shiner and one darter were the sole catch. It is possible that the dead leaves may have been responsible for the color of the water and the low dissolved oxygen values. Reserve alkalinity in this vicinity was much higher than at the mouth.

Cumberland River.—The Cumberland River is formed by the junction of Poor and Clover Forks in the southeastern part of Kentucky.

It flows southwest into Tennessee, then northwest into Kentucky and finally empties into the Ohio River at Smithland, Ky. Its length is about 687 miles. The average slope below Burnside, Ky. (mile 516), is about 0.6 feet per mile. The Cumberland drains an area of roughly 18,000 square miles. The river has been canalized for 331 miles by the construction of 14 locks and dams.

The population of the basin in 1940 was 1,129,000, of which 277,724 were in communities of over 2,500. Over half of these, or 167,402, lived in the city of Nashville.

The principal resources of this area are coal, zinc, iron, limestone and oil. The principal industries are agriculture, products of cement, rayon textiles and chemicals.

Observations were made on the Cumberland River during the months of October and November, 1940. Samples were taken from dam 8 (mile 317) in Tennessee, to dam F in Kentucky, approximately 45 miles from the mouth of the river. Heavy rains occurred during the survey period, but some observations, both before and after the rain, indicated that no important variation was introduced by this factor. Likewise, and unseasonable cold spell occurred toward the end of the period of observation which brought the water temperature in some cases down to 10° C. Both of these conditions, the rain, and the drop in temperature, may affect the absolute values of the samples from dams 4 to 8 and from dams C to F. The center region of the river was studied prior to the onset of the rains and, therefore, may be considered fairly representative of the late summer conditions. The probable effect on the plankton volumes at the two ends of the observation range is not more than 100 percent, which does not affect the general plankton picture of the stream (fig. 13 and table 16).

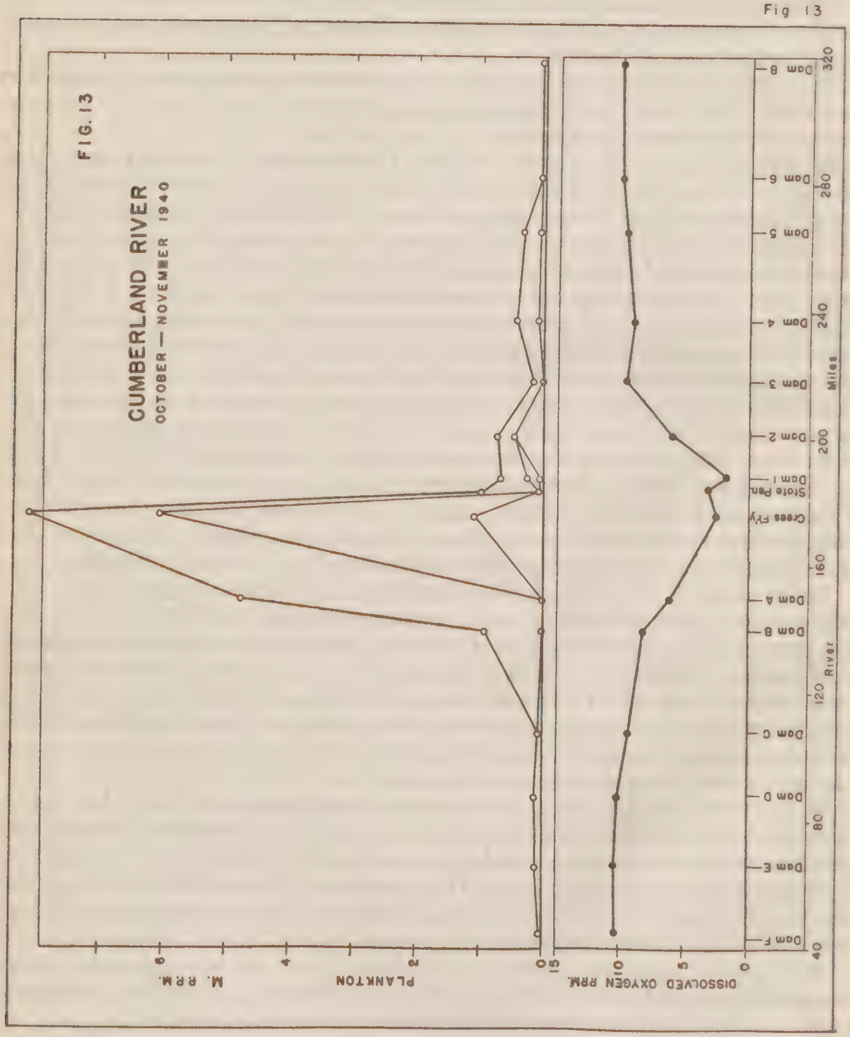
From dam 8 to dam 3 the plankton level was quite low. The slight rise in the values at dam 4 may perhaps be attributed to the discharges from Gallatin and Lebanon, which are situated on small side creeks. From dam 3 to dam A is found a relatively concentrated human population. Between dams 2 and 3 is located a rayon plant, with a grouping of small towns in the vicinity. The city of Nashville, with its large concentrated population, suburbs, and large number of industries, is located just above dam 1.

It is seen that the location of the population is indicated in both the plankton and dissolved-oxygen curves. The plankton commences to rise above dam 2 and reaches a peak some miles below Nashville. This peak, due largely to class II organisms, falls off slowly down the river. The last of this plankton hump is found somewhere below dam B. The State penitentiary, several miles below Nashville, contributes a fair amount of waste. Between this location and the next sampling point, Crees Ferry, is located a paper mill, which causes a very noticeable blackening of the stream below its location.

The oxygen curve shows a distinct drop between dams 2 and 3 and reaches a minimum at dam 1 immediately below Nashville. Recovery is slow, and is not complete before dam B, approximately 48 miles downstream.

The Cumberland River shows in almost diagrammatic form the effect of an isolated source of heavy pollution upon a relatively clean stream. It is possible that if there were no navigation dams, the effect of Nashville pollution would be evident further downstream.

Fig 13



(Note.—For explanation of figures see p. 1287)

The State department of conservation plants fish rather extensively throughout portions of the Cumberland Basin in Tennessee. This may account for some of the specimens found in side streams and, to a certain extent, in the Cumberland River itself. It is evident from the catches, however, that there is sufficient nutritive material to enable the fish to grow to good size.

In fishing the Cumberland River, it was the practice to set the trap net in the current below various dams. Shallower tributaries were seined. At dam 8 an overnight catch consisted of two crappies; at dam 6, crappies to 10 inches in length, Kentucky smallmouth bass to 9 inches, bluegills and sunfish. Other fishermen caught sheepshead, and redhorse suckers. At dam 5 fish were more varied, consisting of crappies, darters, log-perch, shad, and numerous shiners, chubs, and quillback suckers. Bass were undoubtedly present, although none were caught.

Kentucky bass were found at dams 3 and 4, with shad seen in fair numbers. These last fish were eating the algae from the dam and the lock walls. Dam 2 also yielded Kentucky bass and sunfish. Dam 1 was visited twice, once immediately before and once immediately after a rain. Water conditions were very bad at the time of the first visit, the dissolved oxygen being less than 2 parts per million above the dam. Crayfish were found along the bank, approximately half of them being completely out of water, apparently to avoid the asphyxiating conditions in the stream. These crayfish were often very heavily covered with a white growth, presumably fungus. In the lock itself, water, which had been isolated from the river overnight, contained less than 0.7 parts per million of oxygen. Fish were numerous in this water and swam either at the top or close to the top, seeming to prefer the region of the lock walls where algae were growing. They came to the top apparently to gulp air. Some of these fish could be captured by means of a dip net. Among them could be seen catfish and gars of large size, shad, sunfish, minnows, and bass. About 4 days later, following a rain, the oxygen was approximately 6 parts per million and crayfish were no longer visible along the banks.

Sheepshead, numerous Kentucky bass, and crappies were found at dam A, and dam B yielded Kentucky bass. The fish caught at this dam showed very noticeable tail and palate infections. After this find, such infections were watched for in all cases and found to be fairly common, although not quite so numerous, both above and below this point. The State conservation department informed us that this was an infection by fungus with which was associated a species of *Hydra*.

At dam C the water was somewhat muddy, due to the discharge of the Red River, upstream from that point. The net catch consisted of smallmouth buffalo, channel and mud catfish, and a number of sheepshead.

At dam D the catch was Kentucky bass, while at dam E a white bass and a large number of channel catfish were caught. Dam F yielded Kentucky bass and crappies in the fyke net, while shiners and shad were caught in the lock with a dip net. A large white bass was also seen swimming in the lock water. It may be noted that at this dam, which is the site of the western State penitentiary (Eddyville), with a population approaching 2,000, the bass were the fattest found on the river.

Stone River, which enters the Cumberland above Nashville, showed a heavy algal growth. Oxygen was good and a variety of fish were found. The species captured were sunfish, bluegills, Kentucky bass, mud catfish, shiners, darters, smallmouth black bass, log perch, and chubs. Frogs, tadpoles, and salamanders were caught and the crayfish found at this point were very clean and brightly colored. The plankton found was of approximately the same level as the catch at dam 1. Seining conditions at the Harpeth River were not good. Two kinds of minnows were caught. It is reported that a chemical plant empties its wastes into this river. The electrical conductivity of the water was not noticeably higher than that found in Stone River, although samples were taken following a rain. The total plankton was less than 0.1 thousand parts per million.

MAIN OHIO RIVER

The Ohio River is acid from Pittsburgh to mile 172 (below Pittsburgh) at Marietta, although on occasion the effects are felt as far downstream as the mouth of the Kanawha River at mile 266. The River is near neutral (pH 6.9 to 7.4) from Marietta to mile 320. From mile 320 the pH increases slightly to the mouth (7.4 to 8.5). The Ohio seems to be relatively stable chemically and bacteriologically, compared to its tributaries. Cincinnati and, to a lesser extent, Louisville, make their locations known by their effect on the dissolved oxygen, biochemical oxygen demand, and coliform count. With these exceptions, however, and that of a possible gradual increase in biochemical oxygen demand and bacterial count in passing down river, there is relatively little chemical or bacteriological variation. This can be ascribed to the large dilution factor due to the stream size.

A large number of plankton samples was collected from the middle third of the river, from mile 316 (above the mouth of the Big Sandy) to mile 531 (dam 29), in the interval from May 1 to December 28, 1939 (table 17). Fewer samples were taken in the upper and lower thirds in 1940. No fish collections were made.

The plankton of the Ohio River contains fewer genera and species than that of the main tributaries. The plankton volume immediately below Pittsburgh, at the Emsworth Dam, in October 1940, was extremely low, less than 0.1 thousand parts per million, and consisted mainly of *Closteriopsis* and some small green algae. The population fluctuated, with an irregular tendency to increase downstream to Marietta, Ohio (mile 172). The low plankton volume and the limited variety of planktons are correlated with the acidity of the upper portion of the river. During the summer period, the river in the region above Marietta may reach a pH value as low as 4.1, and is usually acid, even in the spring and early summer.

In June and July the plankton volume in the neutral portion of the upper third of the Ohio (below Marietta) was occasionally as high as 4 thousand parts per million, while in August and September the volume remained at lower levels. The most numerous forms in the June–July period were *Chrysococcus*, *Chlamydomonas*, and a variety of green algae (diatoms). *Closteriopsis*, *Chlamydomonas*, and *Cyclotella* dominated the fall plankton in this region.

In the middle third of the Ohio River, in May 1939, a large bloom of diatoms was the striking feature of the plankton. The principal genera involved were *Asterionella*, *Gomphonema*, *Nitschia*, and *Synedra*.

The highest volume value of plankton found was at dam 37 (Cincinnati) on May 12. There were no data from above mile 405 or below mile 531 to indicate definitely whether this bloom was local, general, or was moving downstream. The data at hand suggest that there was a movement of the diatom bloom downstream. The data indicate that in general the plankton population at dams 37, 38, and 39 (below Cincinnati) was greater than at the stations above. This may be attributed to the fertilizing effect of the waste from the Cincinnati area.

The high plankton volumes in the lower part of the river, from mile 600 to mile 730 (1940), are due largely to diatoms, principally *Melosira*, *Synedra*, and *Fragilaria*. *Asterionella* becomes important in the samples near the mouth of the river below mile 800 (November).

The Ohio River seems to possess a plankton population which is characteristically different from that of its tributaries. The outstanding characteristic of the Ohio plankton is the presence of large numbers of diatoms of genera not prominent in the plankton of its tributaries. Modifying this is the acid condition in the upper portion of the river. This results in *Closteriopsis*, the form dominating the acid waters of the Monongahela River, extending its range down through the acid regions of the Ohio River below Pittsburgh.

The equipment on hand was not adequate to make a detailed study of the fishes of the Ohio River. Considerable fishing, however, is done with set lines by the river people, and large catches of carp and channel catfish were reported at various places along the river below Liverpool, W. Va. Many gar pike and mooneyes were seen breaking water at Marietta, Ohio, and Ashland, Ky. Fishing for river chubs is a favorite sport for children along the middle third of the river, and an occasional walleyed pike is taken.

Discussion

Owing to the large area of the Ohio Basin (204,000 square miles) and the short time allotted to the survey (2 years), it was impossible to attempt a completely satisfactory biological study. It is realized that there are inaccuracies in the method of sampling and computation and the danger of misinterpretation due to the small number of samples taken at a given point. It is well know that the biological picture of a stream varies with the year, the season, and even the time of day. While the data cannot be considered complete, the general agreement between series of samples and the support of comparative data strengthen the deductions from a given sample. The long series of samples taken at fixed points in the Ohio Basin from May through December 1939 show the influence of seasonal and climatic factors on the plankton and, through evaluation of these influences, it has been possible to increase the significance of the interpretations of individual samples.

A study of the data presented brings out the following topics for discussion.

ORGANIC POLLUTION

Pollutants which enter streams from city sewers or organic industrial plants, such as canneries, meat-packing houses and creameries, affect the aquatic life in a variety of ways. The waste may have an

immediate toxic effect or, as is more often the case, the waste may induce rapid multiplication of aerobic bacteria which sharply lower the dissolved oxygen concentration, frequently to the asphyxial level for fishes, and often to depletion. This is probably the most common cause of mass death of fish in streams of the Ohio Basin. (See Trautman (5).)

The lowering of the dissolved oxygen concentration, accompanied by high biochemical oxygen demand and a high count of coliform bacteria (if the pollutant is sewage) is evident for a distance, below the source of pollution, which depends upon the temperature, rate of flow, and type of stream. It may vary from a few hundred feet to several miles. Biologically, this region is dominated by class II planktonts, and the fish are principally of the coarse varieties, such as carp and buffalo. Abundant fungi and stalked ciliates may be attached to solid surfaces.

This zone gradually blends into the next, which is characterized by a large variety and volume of photosynthetic plankton organisms and a high diurnal variation in the dissolved oxygen concentration, from supersaturation on some afternoons to very low values before dawn. (See Denham (6), and Butcher, Pentelow, and Woodley (7).) This marks the maximum fertilization effect of the pollution introduced upstream. In this region is usually found a large mixed fish population.

Further downstream, the high concentration of nutritive materials has been greatly reduced by the heavy upstream growth of plankton, and only the thrifty forms persist (Chrysophyceae, Cryptophyceae, and certain diatoms). This reduction in fish food has a direct effect upon the fish population, so that the game fishes are the dominant forms and the numbers of plankton feeders are reduced.

Where proper treatment is given to the wastes before they are turned into the stream, the early obnoxious stages of the natural purification processes are greatly reduced or entirely eliminated. Primary treatment plants, which remove the solid suspended materials from the wastes, result in less sludge being deposited in the stream, and in more immediate and rapid decomposition of the soluble materials. If the effluents are introduced into a stream where proper dilution occurs, conditions may never become obnoxious. If the treatment plant effluent forms a larger portion of the total stream flow, as in the Vermilion River below the Danville treatment plant, conditions may become acute for aquatic life, but the acute conditions are relieved in a comparatively short stretch of the stream, and the fertilization effect predominates.

The aim of secondary treatment of wastes is not only to remove and break down the solid components of the waste, but, by means of trickling filters or activated sludge, to allow a portion of the bacterial action to take place before the waste enters the stream, thus lowering the biochemical oxygen demand of the effluent and presenting it to the stream in a form more available for the plankton. This results in an even more marked reduction of the region of acute conditions and of the time and distance before the peak of the plankton volume is reached. Ideally, there should be no harmful effects from the effluent of a secondary treatment plant on fish life.

In practice the results achieved by this type of treatment are dependent upon the efficacy of the plant and the total amount of

waste treated. Thus, Peru (population 12,000), on the Wabash River, with a secondary treatment plant operating for only a few months before the time samples were taken, showed no obnoxious oxygen conditions and an immediate heavy growth of algae and plankton below the plant effluent. The stream cleared itself of even this index of pollution in a very short distance. On the other hand, Muncie (population 46,000), on the White River, despite extensive corrective measures, contributes a load of residual organic material that is important in relation to the size of the stream at that point, and biological conditions are affected for some distance. On the same river, but at a point where flow volume is somewhat greater, the much larger city of Indianapolis (population 370,000) also affects the river biochemical oxygen demand, dissolved oxygen and biology, but the effect is not in proportion to that at Muncie.

It should be pointed out that the introduction of untreated industrial wastes which are not necessarily available in any form for plankton food, complicates somewhat the natural purification processes. Thus, the entrance of creosoting wastes together with untreated sewage, as in one instance, may greatly slow down the bacterial decomposition of the organic matter, and result in a greater downstream propagation of the obnoxious stages of pollution. In addition, the presence of complicating toxins may appreciably raise the minimum oxygen requirement for fishes (due to increased metabolic rate) and thus cause an oxygen level, which may be ordinarily tolerated, to become definitely lethal.

As has been noted by other workers (8) the presence of high pollution renders the incidence of parasitizations and developmental abnormalities much higher in the fish population. Thus, in the Vermilion River, below Danville, where the fish population was definitely high, parasitized fish and deformed fish were numerous. A more striking example was found in the Big Blue River, a tributary of the White River, where the fish taken below Carthage were all extremely heavily parasitized by organisms causing black or brown spots in the skin. The parasites were found in abundance up and down the stream, which is subject to repeated pollution, but the heaviest incidence of the parasites occurred at the location mentioned.

INDUSTRIAL WASTES

The industrial establishments in the Ohio River Basin, in addition to canneries, creameries, and meat-packing plants are steel mills, coal mines, paper and pulp mills, distilleries and breweries, and oil and gas refineries. The acid wastes from steel mills and coal mines will be discussed separately.

The majority of these plants are situated in the large cities in the heavily populated area, such as along the Miami, Wabash, and Ohio Rivers. Thus, it is difficult to separate the effects of the industrial waste from those of the domestic sewage that is entering the stream at the same location. Often industrial wastes enter the city sewers. The most satisfactory way to determine the effects of industrial effluents is to study small streams on which are located isolated plants. Increase in temperature due to hot effluents must be considered in addition to the chemical nature of the wastes.

Oil and gas refineries are found along the length of the Elk River, from Sutton to the junction with the Kanawha at Charleston. An isolated refinery is found at Huntington, W. Va., at the mouth of the Big Sandy. While the most prominent effect of the pollution is severe tastes and odors in local water supplies, there is an important effect on the fish. (See also Shelford (9).) The Huntington plant causes the flesh of the fish at the mouth of the Big Sandy to taste of petroleum. The pollution along the Elk River has contributed to the absence of fish in that stream (September). The plankton of the Big Sandy is too low to draw any conclusions as to the effect of oil from the Huntington refinery on these organisms. The Elk River plankton is also low, but as the entire river is affected, it is not possible to obtain unaffected samples for comparison.

The effect of coal washeries is shown along the Tug Fork of the Big Sandy. These detract greatly from the suitability of this stream and many small tributaries for fish life. The water is black and a bottom layer of coal particles is deposited for miles below a washery. A few plankton forms, such as *Navicula*, *Chrysococcus*, *Cryptomonas*, and *Chlamydomonas*, are present. These streams are alkaline.

A paper mill and tanneries on the Clarion River, a tributary of the Allegheny in Pennsylvania, discolor the water for many miles downstream. The Allegheny itself was colored for a considerable distance below the entrance of the polluted tributary. The plankton population of the Clarion at Cooksburg in July, 1939, consisted of fair numbers of *Mallomonas*, *Chrysococcus*, *Chlamydomonas* and *Peridinium*. There was a large mixed fish population. The flesh of the fish was tainted, making it inedible. A paper plant below Nashville, Tenn., apparently does not affect the plankton of the Cumberland River, although the stream is blackened.

Another type of pollution, consisting of cellulose and lignin fibers, resulting from paper and strawboard manufacture (the Wabash watershed and others), may clog the gills of fish, causing death; may increase the turbidity to the point of affecting the plankton; may form a sludge layer on the bottom of the stream, and may eventually be attacked by specialized bacteria, and so contribute to the oxygen demand. Many types of plants discharge wastes having a large oxygen demand, resulting in the depletion of oxygen and the killing of many fish annually.

Pollution from plants manufacturing chemicals may be serious in some localities. A plant on the Kanawha River, above Charleston, W. Va., has been the subject of a report by Ellis (10). Another source of industrial pollution upon which data collected during the present survey is insufficient is brine pumpage from oil wells. This is serious, as fresh-water organisms in general are not adapted physiologically to withstand heavy salt concentrations (see Ellis (11)). Tannery wastes may also be important in some localities.

ACID POLLUTION

The entrance of sulfuric acid from active and abandoned coal mines is one of the most important problems of stream pollution throughout the Ohio River Basin. Many abandoned coal mines that have not been sealed are daily pouring tons of sulfuric acid (formed by oxidation of iron sulfides) into these streams (Hodge (12)). Many of the active mines are working only part of the year and, unless pumping is carefully

controlled when operations are resumed, a very heavy load of acid may be discharged into the watercourse. The pH of acid mine drainage streams has been known to reach 2. This low pH eliminates all fish, and only a few plankton forms exist (1). *Euglena mutabilis* may grow in sufficient numbers to form a bright green carpet over the entire bed of small acid streams of pH 4 or less.

Acid streams are characterized by a deposit of yellow to brownish precipitate (iron oxide) that covers the bottom. This deposit may remain long after sealing has prevented air from entering the polluting mines and the source of acid thus eliminated. The bottom of the stream, therefore, remains unsuitable for egg deposition and development of fish and their food organisms, long after the water acidity has been corrected.

The acid drainage, chiefly from mines but also to a lesser extent from the steel mills near Pittsburgh, Wheeling, and Steubenville, lowers the pH of the Ohio River to 6 or less as far downstream as Marietta, Ohio, and is an important factor in the low plankton population in the upper portion of the Ohio River, and the cause of downstream fish migration.

STREAM ZONES

A summary of the observations over the Ohio River watershed shows that streams and regions of streams may be divided into the following five types of zones, according to the dissolved oxygen, pH, plankton, and fish data:

(1) Zone of heavy organic pollution: dissolved oxygen not higher than 3 parts per million even during the daytime; plankton volume variable, principally composed of class II organisms; pH tending toward acidity. Fish mostly absent, occasionally buffalo, carp, and sunfish.

(2) Zone of intermediate pollution: dissolved oxygen between 3 and 5 parts per million in the daytime; plankton volume is higher than in (1), with an increasing number of chlorophyll-bearing forms, although still composed largely of class II organisms; *Oscillatoria* and other blue-green algae common, and a growth of green algae commencing to appear along the stream margin; pH slightly higher. Fish, in addition to carp and buffalo are more abundant, but show a tendency to sickness, deformity, and parasitization.

(3) Fertile zone: dissolved oxygen not below 5 parts per million and subject to diurnal fluctuations; plankton over 1 thousand parts per million (usually several thousand parts per million), and largely green forms, of the intermediate group, marginal growth of algae very noticeable in some places; pH over 7.2 and tending to rise, especially during sunny periods. Fish are variable, plentiful, and healthy; large numbers of suckers, sheepshead, catfish, and other market fish are present.

(4) Game fish zone: dissolved oxygen above 5 parts per million and usually approximating saturation values; plankton usually between 0.3 and 1.0 thousand parts per million, with class II forms scarce; pH neutral to alkaline. Game fish (basses and perches, pike, etc.) and forage fish predominate.

(5) Poor fish zone, due to (*a*) natural conditions, or (*b*) acid pollution: (*a*) Naturally poor fish zone: dissolved oxygen above 5 parts per million and usually approximating saturation values; plankton

less than 0.3 thousand parts per million and consisting almost entirely of class I organisms. Fish are mainly the game fish types. Streams that may be classified by the fisherman as good trout streams are, by the above biological standards, poor streams, i. e., infertile and relatively low in biological population. (*b*) Acid polluted zone: the pH is variable, and the water is sometimes acid. If the stream is highly acid, there may be no fish at all.

The 5 (*a*) type of stream is characteristic of the tributaries coming to the Ohio from the south, where the winter period is not marked, so that there is generally a lower level of, and less seasonal fluctuation in, the aquatic life. It is also true that these streams usually have relatively rocky, infertile watersheds, and are often of the 5 (*b*) type or subject to acid pollution.

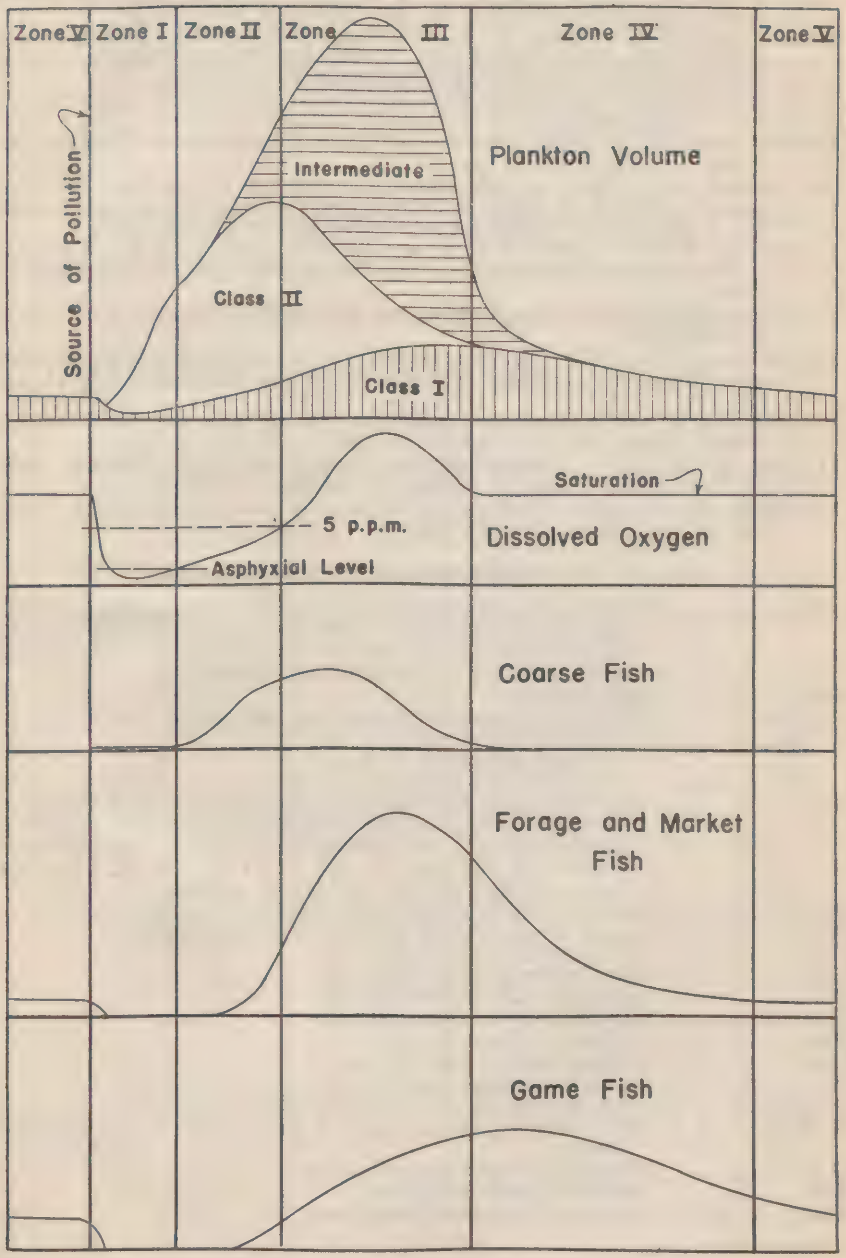
These relationships of the different zones are illustrated graphically in figure 14. The plankton curve shows the dependence of class II organisms upon a rich food supply and that of the intermediate forms upon a less concentrated medium. Pollution affects the class I organisms to a certain extent, but they are less affected by either favorable or unfavorable conditions than are the members of either of the other two groups of planktons. For this reason they are the characteristic forms of "clean waters," as well as persisting through polluted areas.

In the region where the oxygen levels lie between asphyxial values and 5 parts per million, fish normally found in oxygen-poor situations predominate (carp, buffalo). Fish of other types are abnormal under these conditions. Occasional abnormal fish may be found in situations where the dissolved oxygen is over 5 parts per million, when the upstream pollution is very intense. The field results show that the 5 parts per million level seems to form a natural dividing line between good and bad fish conditions, corroborating the findings of Ellis (11). Under certain conditions, the level may be set higher, but there is no evidence that it should be set appreciably lower.

The zones illustrated in figure 14 are shown as possible phases in a continuous situation, although it is understood that in a given stream certain zones may never appear. The Cumberland River, for example, is an almost diagrammatic illustration of the condition depicted, with Nashville serving as the site of pollution. The Miami River, on the other hand, from Dayton downstream, falls entirely in zones (1), (2) and (3). The Wabash River watershed lies in generally fertile, glaciated territory, and its unpolluted regions correspond to zone (4) conditions. Mountain streams, acid streams and, in general, the infertile southern streams in their unpolluted reaches, correspond to zone (5). Light pollution may improve them biologically at local points.

The zone into which a given point of a stream may fall will vary with conditions. During spring high water, for example, zone (1) and (2) conditions are scarce. As the year advances and low-flow conditions set in, the polluted areas are more distinct. It should be stressed that it is the summer low-water period that is critical to the fish population of a stream, and not the favorable high-water conditions. A period which exterminates a fish population may be only 1 day of the year, but it is not compensated by the tolerable conditions of the other 364 days. Likewise, a single epidemic of a water-borne disease renders insignificant the years between it and the previous outbreak.

Fig. 14


Zone V
Zone I
Zone II
Zone III
Zone IV
Zone V
Source of Pollution
Plankton Volume
Intermediate
Class II
Class I
Saturation
5 p.p.m.
Dissolved Oxygen
Asphyxial Level
Coarse Fish
Forage and Market Fish
Game Fish

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Explanation of Tables

Mile---------- Refers to the distance from the junction of the stream with the Ohio, except the White River (Table 14) where it refers to the distance from its junction with the Wabash. The mileage of the Ohio River is taken from Pittsburgh, Pa.

Samp---------- Samples taken.

Volume: Plankton in thousands of parts per million (M. p. p. m.).

- T---------- Total plankton M. p. p. m.
- I---------- Class I organisms M. p. p. m.
- II---------- Class II organisms M. p. p. m.

Ave---------- Average volume, determined by dividing the total volume of plankton by the number of samples; or the total number of organisms of the various groups, divided by the number of samples; or the total B. coli, B. O. D., D. O., Tby., pH, Temp., divided by the number of samples.

Max---------- Highest value obtained during period under question.

Min---------- Lowest value obtained during period under question.

Chr---------- Chrysophyceae, numbers per ml.

Cry---------- Cryptophyceae, numbers per ml.

Chl---------- Chlorophyceae, numbers per ml.

Myx---------- Myxophyceae, numbers per ml.

Bac---------- Bacillarieae, numbers per ml.

Eug---------- Euglenophyceae, numbers per ml.

Pro---------- Protozoa, numbers per ml.

B. Coli---------- Coliform bacteria, most probable numbers per ml.

B. O. D---------- Biochemical oxygen demand, 5 days at 20 °C., in parts per million.

D. O---------- Dissolved oxygen, parts per million.

Tby---------- Turbidity, parts per million.

Temp---------- Temperature, degrees Centigrade.

TABLE 1.—*Big Miami River*

Station	Mile	Date, 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
				Ave.	3.0	0.93	0.63	103	47	409	11	996	23	18	217	3.61	8.70	60	7.9	17.0
Cleves	4.2	May 16 to Dec. 12	22	Max.	9.8	4.6	3.6	584	504	1,045	46	7,857	84	52	930	5.34	10.00	310	8.3	26.0
				Min.	.21	.07	.05	20	0	28	0	56	0	0	21	1.25	6.67	8	7.6	5.0
				Ave.	8.2	3.5	1.3	84	169	972	7	3,206	73	41	303	4.58	8.41	30	8.1	22.3
Venice	24.8	May 1 to June 28	6	Max.	16.9	7.7	2.7	352	340	2,384	36	9,044	276	84	930	5.84	9.82	40	8.3	26.5
				Min.	4.7	.38	.66	4	60	116	0	260	4	18	36	2.57	6.61	20	8.0	14.0
Hamilton:																				
				Ave.	5.6	1.6	1.4	48	144	651	22	2,255	224	26	389	3.45	5.77		7.7	24.9
Above	35.9	June 28 to Sept. 15	4	Max.	15.8	5.0	4.8	124	476	1,448	36	7,440	708	62	930	4.20	6.43		7.7	26.5
				Min.	1.8	.04	0	6	4	152	4	36	28	0	46	2.31	4.78		7.6	23.5
				Ave.	5.2	1.4	2.2	108	72	611	41	2,047	119	85	2,747	5.02	4.93		7.6	23.5
Below	30.4	July 21 to Oct. 27	6	Max.	8.4	4.2	4.7	216	138	898	84	6,384	162	292	11,000	11.72	6.95		7.8	27.5
				Min.	.76	.06	.34	15	4	60	8	36	62	12	430	1.46	1.90		7.5	19.0
Middletown:																				
				Ave.	3.0	1.1	.4	99	106	558	31	1,522	84	24	257	4.81	8.44		7.7	23.1
Above	57.0	June 27 to Sept. 29	4	Max.	8.4	2.1	2.7	224	293	1,646	64	3,254	153	40	750	7.43	12.07		7.9	25.0
				Min.	1.0	.25	.32	16	16	68	2	36	40	3	36	2.38	7.05		7.4	20.5
				Ave.	4.3	.96	1.8	75	65	492	18	1,313	61	20	1,326	5.70	5.26		7.7	23.9
Below	50.8	June 28 to Oct. 27	7	Max.	10.2	1.8	6.5	204	100	1,184	56	3,492	252	40	4,600	9.60	6.19		7.9	26.5
				Min.	1.3	.15	.09	0	8	52	0	20	4	4	390	2.87	3.54		7.5	19.0
Franklin:																				
				Ave.	7.6	.95	4.8	57	74	488	43	880	271	65	573	3.38	7.43		8.0	23.8
Above	62.8	July 11 to Sept. 14	6	Max.	29.1	2.3	23.6	168	124	874	56	88	796	116	2,400	4.17	7.57		8.2	26.5
				Min.	1.7	.46	1.1	0	20	72	12	32	64	4	36	2.28	7.13		7.9	22.0
				Ave.	8.3	1.0	4.2	168	135	726	54	991	225	93	4,472	5.00	6.15		7.8	23.4
Below	59.6	July 11 to Oct. 26	7	Max.	22.2	1.3	18.6	680	195	1,268	89	2,364	563	276	11,000	8.50	7.05		7.9	26.5
				Min.	2.9	.73	.07	9	60	78	0	74	40	16	91	2.72	4.10		7.6	22.0
Miamisburg:																				
				Ave.	8.0	2.1	2.2	88	133	464	79	1,001	146	35	558	2.94	7.71		8.1	23.0
Above	71.6	June 27 to Oct. 26	9	Max.	15.0	10.7	12.4	322	456	876	244	2,834	186	68	2,400	4.06	9.50		8.2	26.5
				Min.	1.4	.19	1.5	4	12	76	8	56	32	4	91	1.86	6.83		8.0	17.0
				Ave.	4.9	.79	2.3	59	113	453	29	612	200	42	2,214	4.22	5.88		7.9	23.0
Below	66.5	do	9	Max.	10.9	1.3	9.0	96	436	1,476	102	2,368	578	100	11,000	6.73	6.97		8.0	26.0
				Min.	1.2	.20	.30	3	16	45	4	0	32	3	430	2.41	4.70		7.7	17.0
Phoneton	97	July 24	1		5.7	2.9	.28	12	34	684	74	958	59	4					8.0	25.0
Tippecanoe City:																				
Above	108	do	1		4.8	.96	.64	260	0	1,084	72	1,644	12	292	29	5.36	5.96	48	7.9	22.5
Below	103	do	1		6.5	1.3	.33	216	8	1,398	215	2,208	32	48	460	4.46	4.64	37	7.8	24.0
Troy:																				
Above	114	Sept. 14	1		4.8	.76	1.6	88	4	1,097	268	1,346	140	0	36	4.99	10.67	35	8.3	27.0
Below	112	do	1		2.4	.48	.77	52	4	632	140	716	64	0	43	3.59	3.09	25	8.0	27.0

TABLE 1.—*Big Miami River*—Continued

Station	Mile	Date, 1939	No. of Samp.	Volume			Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
				T	I	II													
Piqua:																			
Above	123	Sept. 13	1	1.6	.96	.16	144	4	436	120	1,420	44	12	93	2.08	10.80	35	8.3	21.0
Below	120	do	1	1.6	.24	.29	128	8	420	76	588	56	8	2,400	7.64	7.61	25	8.1	13.5
Sidney:																			
Above	137	do	1	1.2	.67	.17	200	0	220	24	388	72	4	9.1	2.09	9.02	38	8.1	19
Below	132	do	1	14.0	12.1	1.0	140	0	132	100	3,618	80	0	11,000	8.44	7.27	25	8.1	20
Loganville, below	155	July 25	1	1.4	.04	.83	0	2	72	72	38	24	2					7.6	26
Russel Point	164	do	1	1.2	.12	.28	9	9	152	540	138	39	3					7.8	
WHITEWATER RIVER																			
Harrison:																			
Above		July 13	1	2.9	.38	.33	40	188	772	0	152	80	24	15	0.94	7.77			24.0
Below		do	1	5.1	.79	.54	24	568	1,708	8	284	86	8	93	1.31	8.00			23.5
Brookville:																			
East Fork:																			
Above		do	1	4.4	.94	1.2	12	164	548	0	484	156	0	24	.99	9.08			23.5
West Fork:																			
Above		do	1	3.1	2.0	.16	20	80	312	4	218	30	12	9.3	.89	9.30			24.5
Below		do	1	.62	.18	0	16	63	254	3	134	23	0	930	1.07	7.85			23.5
Connersville, below		Aug. 9	1	.98	.55	0	36	60	60	0	168	12	0	430	1.60	6.95			24.0
Cambridge City:																			
Above		July 12	1	1.6	1.4	1.0	4	8	32	0	344	12	4	93	.90	10.34			22.0
Below		do	1	1.7	1.1	.29	10	60	140	5	375	50	0	93	.90	11.51			22.5
Hagerstown:																			
Above		do	1	.57	.51	0	0	0	15	0	165	0	0	23	2.05	11.40			23.0
Below		do	1	.99	.85	.06	25	5	30	0	343	30	10	29	.77	8.75			20.5
Richmond:																			
Above		do	1	7.1	6.7	.24	0	30	45	0	530	25	10	93	1.34	7.78			23.5
Below		do	1	16.2	12.1	3.6	5	70	95	5	1,580	300	5	150	2.75	7.97			22.0
STILLWATER RIVER																			
Englewood, above		July 24	1	3.1	.55	.76	15	101	444	15	42	147	0					7.8	
West Milton:																			
Above		Sept. 15	1	.92	.44	.18	336	0	248	0	752	24	12	23	3.03	8.15	37	8.0	22.5
Below		do	1	1.1	.45	.02	498	0	187	28	492	11	8	93	3.02	6.88	51	7.9	22.5
Covington:																			
Above		Sept. 20	1	.87	.42	.24	172	8	32	0	4	8	12	24	2.12	6.45	70	8.0	15.0
Below		do	1	.79	.20	.09	280	25	116	4	76	20	16	910	2.08	4.84	33	7.9	17.0

MAD RIVER																				
Springfield, above		July 25	1		.24	.23	0	0	3	0	0	105	0	3						
Do		July 24	1		.59	.58	0	0	40	30	0	255	0	0					7.8	20.0
Springfield, below		Sept. 12	1		6.2	6.2	0	0	4	4	8	628	4	4	460	2.44	8.38	10	7.8	18.0
Urbana:																				
Above		Sept. 14	1		2.6	2.6	0	0	0	8	0	260	0	0	15	1.40	8.94	10	7.9	20.0
Below		do	1		1.9	1.9	0	0	0	0	0	649	0	0	430	2.65	7.93	10	7.9	21.5
Do		July 25	1		2.1	2.1	0	12	0	0	0	222	0	3					7.8	22.0
West Liberty		July 24	1		.31	.23	0	0	0	12	0	90	3	0					7.8	25.0

TABLE 2.—*Little Miami River*

Station	Mile	Date 1939	No. of Samp.	Volume				Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.
				T		I	II												
Beechmont	------	May 5 to Nov. 20	14	Ave	4.0	0.77	0.86	517	86	791	11	335	80	32	3, 155	5.53	6.25	7.6	17.1
				Max	14.7	2.0	4.3	2, 302	196	6, 724	40	1, 720	304	64	1, 100	13.62	12.50	7.8	25.5
				Min	.75	.13	.02	0	0	54	0	0	0	0	91	1.63	1.53	7.5	0
Milford, above	14.2	Nov. 20	1	--------	6.0	5.9	.04	88	24	12	0	444	0	8	24	1.32	11.84	8.0	7.0
Milford	13.5	July 18 to Aug. 15	3	Ave	1.8	1.1	.21	34	65	164	7	1, 101	24	21	158	1.70	7.54	-----	24.0
				Max	3.7	2.6	.36	88	116	324	20	3, 136	32	40	230	1.87	8.00	-----	26.5
				Min	.76	.29	.00	7	20	44	0	63	0	0	93	1.41	7.10	-----	22.5
Milford, below	13.3	Aug. 28 to Nov. 20	3	Ave	2.3	.73	.27	449	39	951	11	103	46	24	54	2.43	9.51	8.1	16.5
				Max	2.6	2.0	.65	748	60	2, 262	24	304	76	30	93	3.09	11.58	8.2	23.5
				Min	2.2	.05	.02	117	24	44	0	0	0	8	23	1.32	7.98	8.0	6.0
Loveland: Above	24.6	July 17 to Nov. 20	4	Ave	4.1	.74	.80	262	100	1, 239	6	131	85	8	19.4	2.71	10.06	8.0	18.3
				Max	7.4	1.5	1.7	480	296	2, 934	24	372	171	12	36	4.48	12.20	8.1	24.0
				Min	1.5	.07	.10	48	28	68	0	12	7	2	.73	1.73	7.90	7.9	6.5
Below	23.6	do	3	Ave	3.6	1.7	.30	191	77	474	4	466	36	12	24.8	1.97	10.18	8.1	18.2
				Max	4.7	4.2	.37	432	159	924	12	1, 169	60	20	36	3.12	11.90	8.1	25.0
				Min	2.4	.15	.26	12	24	68	0	6	8	4	2.3	1.06	7.93	8.0	7.0
Kings Mills	31.2	Aug. 2 to Nov. 22	4	Ave	2.0	.71	.58	111	46	456	8	132	64	18	14.7	1.46	9.09	8.0	19.3
				Max	4.4	2.0	.25	160	96	1, 620	4	232	112	52	36	1.82	11.34	8.1	24.5
				Min	.62	.21	.00	60	12	44	0	8	1	4	4.3	1.03	7.83	7.9	6.5
South Lebanon	33.8	Aug. 2 to Sept. 27	3	Ave	2.1	.27	.79	153	75	272	0	57	81	8	45	1.32	7.85	7.9	25.0
				Max	4.9	.43	1.8	264	174	724	0	148	112	20	91	1.58	8.17	7.9	28.5
				Min	.47	.11	.16	4	12	36	0	0	64	4	9	1.05	7.40	7.9	23.0
Yellow Springs: Above	82.0	Aug. 25 to Nov. 17	4	Ave	.92	.50	.04	8	7	79	0	29	4	3	19.6	.82	8.53	7.8	13.8
				Max	1.4	1.3	1.05	16	16	228	0	72	12	8	46	.99	10.07	8.1	21.5
				Min	.10	.00	.01	0	0	4	0	0	0	0	.91	.61	7.37	7.6	7.0
Below	81	Sept. 22 to Nov. 17	3	Ave	3.2	.10	.19	11	12	165	0	40	10	7	9.74	.88	10.53	7.9	9.5
				Max	9.2	.16	.48	12	16	474	0	62	28	12	.24	1.26	12.98	8.0	14.0
				Min	.19	.05	.05	8	0	0	0	16	0	0	.91	.54	8.48	7.9	4.5
South Charleston	96.5	Sept. 7	-------	--------	.94	.62	.26	28	56	24	0	192	24	8	36	1.53	6.55	7.9	19
Do	96.5	Oct. 4	-------	--------	35.9	1.2	31.2	0	4	15	0	636	2, 830	0	110	5.53	9.50	8.3	20.5
Do	99	Sept. 7	-------	--------	2.2	2.0	.08	16	0	24	16	610	30	12	150	4.35	3.95	7.9	18.0
Do	99	Oct. 4	-------	--------	.74	.66	.06	0	0	16	4	136	72	0	460	2.49	7.53	7.9	18
EAST FORK																			
South Milford	------	July 18 to Nov. 21	5	Ave	1.5	.51	.28	1, 452	82	183	0	46	145	6	37.5	2.04	7.81	7.6	19.3
				Max	3.3	1.4	.90	6, 492	268	336	3	51	446	15	73	2.40	11.24	7.7	23.5
				Min	.14	.02	.00	36	4	20	0	4	16	0	1.5	1.80	5.63	7.6	7.5
Batavia, below	------	July 31 to Nov. 21	3	Ave	2.61	.28	1.33	1, 651	133	59	5	28	140	35	162	2.88	5.46	7.5	16.3
				Max	7.1	.56	2.0	2, 360	356	20	8	80	356	44	430	3.84	7.02	7.5	23.5
				Min	.29	.02	1.8	40	0	4	0	0	16	24	9	1.37	4.43	7.5	6.5

Williamsburg: Above	46.2	June 30 to Nov. 21	4	Ave	1.2	.73	.5	1,220	80	247	2	23	106	28	18	2.42	7.98	7.6	18.3
				Max	3.9	1.4	1.7	2,927	144	568	8	48	240	100	36	3.53	10.37	7.7	25.0
				Min	1.6	.08	.21	40	24	22	0	0	0	0	2.4	.66	6.52	7.5	6.5
Below	45	do	5	Ave	1.7	1.3	1	535	330	314	0	36	96	15	341	3.99	6.85	7.5	19.3
				Max	8.9	5.0	2.9	2,236	1,344	716	0	84	388	28	1,100	10.98	7.52	7.6	25.0
				Min	.44	1.03	.36	12	24	132	0	0	8	8	36	1.45	6.16	7.4	6.0
Lynchburg: Above		Oct. 9	1		1.7	.1	.55	1,106	4	24	0	8	152	32	23	3.50	2.53	7.7	20.0
Below		do	1		.37	.01	.09	112	4	16	0	0	72	12	4.3	3.18	5.56	7.8	21.0
TURTLE CREEK																			
South Lebanon	34.2	July 19 to Sept. 27	3	Ave	26.2	.30	.73	50	61	618	0	99	23	28	135	3.02	7.00	7.9	20.0
				Max	77.3	.72	.38	100	92	1,716	0	330	32	76	230	5.37	7.27	7.9	22.5
				Min	.35	.07	.02	3	28	72	0	12	8	0	24	1.22	6.60	7.9	16.5
Lebanon: Above		July 19 to Nov. 22	5	Ave	5.5	1.5	.98	291	850	641	0	220	122	30	84	2.30	6.35	7.5	16.8
				Max	18.3	3.5	2.3	760	3,964	3,592	3	844	464	52	230	4.62	8.00	7.6	21.5
				Min	1.0	.60	0	6	0	32	0	4	12	8	2	1.33	5.42	7.5	8.0
Below	37.8	do	4	Ave	1.3	.44	.56	6	------	45	11	140	29	66	43,000	25.04	2.44	7.5	17.1
				Max	2.4	1.6	1.6	16	3	87	24	495	44	208	150,000	79.30	4.70	7.5	21.5
				Min	.37	.03	0	0	0	8	0	16	16	4	2,400	2.32	0	7.5	7.0
CAESAR CREEK																			
Jamestown: Above	78.5	Aug. 14 to Aug. 25	2	Ave	2.8	1.2	.53	6	20	212	28	406	176	336	568	5.89	3.25	7.5	20.0
				Max	4.3	1.8	.65	8	40	336	56	608	292	668	1,100	8.70	3.42	7.5	23.0
				Min	1.3	.65	.40	4	0	8	0	204	60	0	36	3.07	3.07	7.5	17.0
Below	76.5	do	2	Ave	2.4	.5	1.1	0	6	164	0	163	180	2	345	5.12	2.50	7.7	20.3
				Max	2.6	.86	1.2	0	12	320	0	280	252	4	460	5.28	3.14	7.7	22.5
				Min	2.2	.14	.88	0	0	8	0	45	72	0	230	4.95	1.85	7.7	18.0
SHAWNEE CREEK																			
Xenia: Above	80.6	June 29 to Nov. 17	7	Ave	2.9	.62	2.0	4	7	63	2	149	58	6	217	1.52	7.03	8.0	16.8
				Max	12.0	1.9	10.8	20	40	144	8	444	304	20	1,100	2.91	11.34	8.1	24.5
				Min	.34	.02	0	0	0	0	0	12	0	0	4.3	1.01	4.46	7.8	6.5
Below	78.1	do	4	Ave	.98	.52	.05	5	0	98	0	185	12	1	3,147	4.71	4.17	7.5	14.9
				Max	2.0	1.8	.13	12	0	368	0	640	38	3	11,000	5.38	7.27	7.6	21.5
				Min	.11	.07	0	0	0	0	0	28	0	0	43	3.69	2.44	7.3	7.5
Do	76.1	July 17 to Nov. 17	6	Ave	2.2	.86	1.1	1	3	33	13	176	18	5	8,420	6.55	5.76	7.9	15.7
				Max	8.4	2.6	5.4	4	12	88	36	944	48	16	46,000	7.83	6.53	8.0	23.5
				Min	.48	.08	0	0	0	0	0	36	0	0	240	5.61	3.87	7.7	8.0
LYTLE CREEK																			
Wilmington: Above	66.5	June 29 to Oct. 2	6	Ave	3.3	1.0	1.3	10	45	111	0	127	56	21	689	3.19	5.62	7.5	20.2
				Max	7.4	2.0	4.3	40	224	504	4	284	222	72	2,400	8.94	9.08	7.5	24.5
				Min	.25	.16	0	0	0	12	0	32	16	0	91	1.04	0.51	7.5	15.0
Below	59.5	do	6	Ave	3.2	1.4	.05	7	16	231	0	413	73	6	1,116	6.71	8.08	8.0	20.9
				Max	4.7	3.8	1.6	20	92	856	4	760	276	12	4,600	23.40	12.90	8.2	25.5
				Min	.92	0	0	0	0	24	1	32	21	0	36	1.32	0.21	7.7	13.5

TABLE 3.—*Licking River*

Station	Mile	Date, 1939	No. of Samp.	Volume T		Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli.	B. O. D.	D. O.	Tby.	pH	Temp.
Latonia	5.5	May 3 to Nov. 13	9	Ave	0.99	0.15	0.14	453	22	192	0	543	17	12	157.2	1.56	8.34		7.66	18.6
				Max	3.1	.28	.39	3,472	71	704	0	4,526	54	44	1,100.0	2.13	11.40		7.8	26.0
				Min	.18	.02	0	0	0	24	0	4	0	0	2.3	.97	6.50		7.5	5.0
Falmouth	51.5	May 3 to Sept. 18	7	Ave	.64	.09	.15	36	14	93	0	26	20	4	73.9	1.52	7.58		7.8	21.2
				Max	2.45	.23	.67	97	28	320	4	76	68	12	460.0	2.03	9.55		7.8	26.0
				Min	.22	.01	0	2	0	20	0	0	2	0	2.3	1.01	7.58		7.8	15.5
Claysville, above	83	Sept. 18	1		.33	.02	.01	8	20	80	0	0	12	0	46.0	1.71	8.48	54	7.9	26.0
Blue Lick:																				
Above	100	do	1		.38	.04	.02	104	4	68	0	8	40	12	2.3	2.32	5.92	32	7.5	23.5
Below	96	do	1		.10	0	.04	32	0	16	8	0	20	4	2.4	1.33	6.27	37	7.4	23.5
Flemingsburg, below		Sept. 19	1		5.1	.04	3.0	0	48	124	28	0	2,184	20	150.0	7.96	5.90	36	7.8	20.0
Morehead, below		do	1		9.1	.68	1.1	1,172	604	4	0	0	4,144	8	23.0	3.30	2.16	11	6.9	20.5
SOUTH FORK																				
Falmouth		May 9 to Sept. 18	8	Ave	3.3	.21	1.37	23	79	585		21	126	7	67.7	2.17	7.87		7.8	23.5
				Max	13.8	.67	7.2	84	180	1,752	12	103	666	16	240.0	3.31	9.64			27.5
				Min	.44	.02	.07	0	0	28		0	5	0	2.3	1.14	6.92			20.0
Farmers	170	Sept. 19	1		.56	.08	.10	1,168	20	44	4	0	12	4	3.6	.63	6.49	14	7.3	20.5
Lair:																				
Above		Sept. 13	1		2.9	1.09	.34	156	72	2,716	0	4	109	8	3.6	2.15	5.44	76	7.9	21.5
Below		do	1		3.6	.04	.89	160	32	1,780	0	0	163	76	3.6	1.63	6.70	76	7.8	24.5
Cynthiana:																				
Above		do	1		.85	.06	.23	80	36	380	0	8	84	4	23.0	1.53	4.24	39	7.6	22.0
Below		do	1		4.7	.04	2.4	12	36	120	0	40	308	8	2.0	2.99	12.67	22	8.6	25.5
Paris:																				
Above		Sept. 12	1		3.1	0	1.3	0	36	560	0	0	104	16	3.6	1.49	6.87	12	7.8	24.5
Below		do	1		23.4	.50	.83	0	240	892	0	13	76	22	36.0	5.30	5.06	30	7.8	20.5
Do		Sept. 22	1		17.4	.17	7.8	0	184	524	0	0	2,206	12	46,000.0	41.15	0	51	7.4	22.0
Mount Sterling:																				
Above		Sept. 12	1		.24	.02	0	45	0	132	4	4	0	0	36.0	5.39	9.10	80	7.9	20.5
Below		Sept. 22	1		.11	0	.01	4	0	20	0	0	12	0	110,000.0	41.07	0	28	7.5	15.5
STRODES CREEK																				
Winchester:																				
Above		Sept. 12	1		.11	.01	0	128	4	4	0	0	8	4	36	3.03	4.11	20	7.6	16.0
Below		Sept. 22			.12	.10	.02	8	4	16	0	32	4	0	3.6	3.12	3.55	17	7.6	22.0
BRUSH CREEK																				
Carlisle, below		Sept. 13	1		.15	0	.07	4	0	12	0	4	16	0	23	1.52	7.37	15	7.6	25.0

TABLE 4.—*Kentucky River*

Station	Mile	Date 1939	No. of Samp.	Volume				Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	B. O. D.	D. O.	Tby.	pH	Temp.
				T		I	II													
Carrollton		May 2 to Nov. 30	21	Ave.	1.3	0.26	0.06	16	25	146	4	114	17	9	4.41	1.52	7.39	47	7.6	20.4
				Max.	10.2	1.4	.46	100	116	1,256	44	540	140	24	11.0	3.39	9.90	340	8.1	26
				Min.	.13	.01	0	0	0	0	0	12	0	0	.39	.63	5.41	6	7.3	9
Gratz	29	Aug. 21	1		1.6	.08	.06	8	64	176	0	48	17	0					6.9	26
Frankfort:																				
4 miles below	63	Sept. 27	1		1.6	1.1	0	8	8	36	8	87	4	64	93.0	2.57	3.39	18	7.3	23.5
Dam	65	do	1		1.3	1.3	0	0	4	14	4	2,098	0	24	240.0	2.40	6.56	13	7.8	23.5
1 mile above	66	do	1		.92	.89	0	0	20	12	0	1,542	4	4	43.0	2.05	8.74	15	8.1	24
Camp Nelson	135	Sept. 28	1		.99	.50	0	0	548	96	4	24	0	8	3.6	1.83	7.64	12	7.7	23
Irvine, below	217.1	Sept. 29	1		.09	.01	.04	96	0	0	0	0	24	0	9.3	1.88	5.71		7.2	25
Ravenna, above	221	do	1		1.2	.72	.16	1,128	4	20	0	0	30	8	2.3	2.95	7.40		7.1	24.5
Beattyville	254.8																			
Above		do	1		.34	.03	.19	425	0	0	0	0	60	4	240.0	2.06	7.46		7.3	25
Below		do	1		.24	.04	.07	332	4	48	0	0	45	0	9.3	2.21	6.71		7.2	24.5
Jackson	305																			
Above		Oct. 17	1		.12	.02	0	276	4	4	0	0	0	4	9.3	1.51	10.33	16	7.5	11.5
Below		do	1		.45	.13	.26	1,082	36	16	12	0	35	12	3.6	3.25	7.97	34	7.6	11.5
Chavies	335.8																			
		do	1		.14	.07	.07	1,124	8	0	0	0	4	0	.9	1.91	10.96		7.6	17
Hazard:																				
Above		Oct. 16	1		.41	.29	0	1,380	28	28	4	0	12	8	46.0	2.26	9.23		7.7	9
At		do	1		1.24	.19	.03	800	12	4	20	0	16	4	150.0	1.62	7.89	17	7.4	9.5
Below		do	1		.12	.05	.05	240	0	4	24	0	8	0	4,600	8.82	3.31	13	7.3	8.5
Whitesburg	404																			
Above		Oct. 19	1		.01	0	0	4	0	0	0	0	8	0	9.3	.98	9.84	5	7.9	10
Below		do	1		.27	.20	.02	0	0	0	0	68	0	28	460.0	1.36	5.07	14	7.7	11
SOUTH FORK																				
Manchester	299																			
Above		Oct. 16			.21	.03	0	320	4	0	8	0	88	4	9.3	1.67	6.68	12	7.2	13
Below		do			.54	.11	.04	130	112	92	0	0	4	16	93	1.91	4.52	5	7.2	9
Big Creek	299	Oct. 6			1.7	1.3	.06	2,593	8	64	0	0	48	32	.36	1.60	8.78	28	7.3	11
Jackson, above	310.4	Oct. 17			1.4	.27	.24	1,200	96	20	0	48	36	22	240	1.88	9.85	12	7.2	11
Hyden, below	327.6	Oct. 16			.02	0	0	36	0	8	0	0	0	8	7.3	.86	9.17	11	7.3	10.5
Blackey	387.6	Oct. 20			.01	0	0	60	0	4	0	0	0	0	24	.78	10.10	5	7.5	14.5
Neon		Oct. 18			.85	.70	.03	28	0	36	8	276	8	4	240	3.03	8.31	14	7.9	12
Cornettsville		Oct. 20			.12	.07	0	594	40	12	0	0	12	0	9.3	1.78	6.60	8	7.3	10.5
Haddux	314	Oct. 17			.02	.01	0	188	0	0	0	0	0	4	4.3	.96	10.0	15	7.8	12

TABLE 5.—*Big Sandy River*

Station	Mile	Date 1939	No. of Samp.	Volume				Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	B. O. D.	D. O.	Tby.	pH	Temp.
					T	I	II													
Dam 1	0.3	June 14 to Nov. 27	18	Ave	1.0	0.07	0.61	36	98	147	3	43	65	10	117	1.36	6.72	44	7.5	24.1
				Max	3.0	.28	2.3	213	336	512	9	200	292	32	460	2.09	8.88	250	7.8	29
				Min	.13	.01	0	0	0	0	0	0	0	0	7.5	.77	4.85	.5	7.1	10
Dam 3	26.6	June 14 to Oct. 13	7	Ave	.27	.14	.09	94	54	21	0	10	13	13	140	.89	7.84	8	7.7	24.9
				Max	.77	.32	.21	296	328	56	4	30	26	16	240	1.14	8.20	12	8.0	29
				Min	.08	.01	0	0	0	0	0	0	0	0	3.6	.53	7.39	6	7.0	19.5
TUG FORK																				
Dam 1	3.8	Oct. 13	1		.11	.03	0	32	0	4	0	18	0	0	4.3	0.96	9.08			14
Kermit:																				
Above		Nov. 24	1		.29	.02	.12	248	8	48	0	0	0	4	2.3	2.48	10.81	5	7.8	6
Below	35.5	do	1		.17	.05	0	272	28	32	0	4	0	0	36	1.87	10.77	5	7.6	6.5
Williamson:																				
Above	57.1	Nov. 19	1		.66	.66	0	140	4	40	0	16	0	12	3.6	.82	11.56	5	7.8	7
Below		Nov. 8	1		.25	.05	.20	60	52	12	0	0	0	12	1,100	1.58	8.94	5	7.7	8
Matowan	98	Nov. 24	1		.18	.02	0	80	12	44	0	12	0	0	4.3	1.97	11.54	5	7.7	6.5
Iaeger:																				
Above	136	Nov. 20	1		2.5	2.0	0	0	4	32	0	304	0	0	4.3	2.48	11.86	7	8.4	7.5
Below		do	1		2.0	1.95	.02	12	8	12	0	536	0	4	1,100	3.18	12.42	5	8.4	8
Welch:																				
Above	159	Nov. 9	1		.53	.53	0	8	0	0	0	204	0	0	9.3	2.60	14.78	5	7.5	9
Below		do	1		.50	.10	.40	0	0	0	0	40	0	44	460	11.40	8.79	18	8.1	11.5
Gary	168	do	1		.02	.02	0	0	0	0	0	8	0	0	240	5.76	11.26	5	7.6	9
LEVISA FORK																				
Louisa		Sept. 29	1		.27	.04	.12	420	0	260	0	0	4	32	.9	0.54	7.80			22.5
Wallbridge	2.7	Oct. 13	1		.42	.30	0	592	0	124	0	48	0	0	4.3	.95	6.68			17.5
Paintsville:																				
Above	38.6	Nov. 28	1		.25	.05	.20	384	24	0	0	0	0	12	7.5	1.27	11.33	7	7.4	4
Below		do	1		.04	.04	0	304	4	0	0	8	0	0	240	1.70	10.98	12	7.3	4
Van Lear		Nov. 29	1		.46	.17	0	740	124	24	0	4	0	8	.4	1.86	12.01	11	7.3	3.5
Prestonburg:																				
Above		Nov. 24	1		1.4	.29	1.0	1,398	228	12	0	0	4	20	3.6	1.55	10.80	17	7.2	7
Below	54.9	do	1		.22	.19	0	948	148	8	0	0	0	0	150	1.57	10.61	20	7.1	7
Boldman, below	77.3	Nov. 9	1		.18	.11	.05	784	68	8	0	4	4	8	3.6	3.39	13.41	16	7.9	12
Pikeville:																				
Above	88.5	do	1		.29	.27	0	3,552	32	4	0	4	5	4	3.6	.56	11.27	18	7.3	5
Below		do	1		1.9	.41	1.4	4,040	132	12	0	32	8	24	1,100	3.58	8.62	12	7.2	8
Millard, above		Nov. 6	1		.64	.47	.09	1,010	76	0	0	8	16	8	3.6	1.45	10.73	30	7.2	5.5

TABLE 6.—*Little Sandy River*

Station	Mile	Date, 1939	No. of Samp.	Volume				Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
					T	I	II													
				Ave	0.29	0.08	0.11	61	37	18	0	13	6	8	167.2	0.95	7.35	43	7.4	21.1
Greenup	0.1	June 14 to Nov. 24	18	Max	1.5	.66	1.2	146	264	40	4	52	36	24	1,100.0	1.47	9.90	160	7.9	25.5
				Min	.02	0	0	0	0	0	0	0	0	0	3.6	.54	6.26	6	7.2	6.5
Grayson:				Ave	.09	.04	.03	404	5	0	0	4	3	9	14.1	.90	6.63	25	7.6	14.5
Above	24	Sept. 8 to Nov. 29	4	Max	.19	.07	.12	896	20	0	0	12	10	16	24.0	1.11	7.10	30	7.8	22.0
				Min	.06	.01	0	0	0	0	0	0	0	0	9.1	.58	6.29	22	7.5	3.0
				Ave	.30	.06	.22	382	4	6	0	0	17	14	460.0	1.43	5.71	31	7.6	14.4
Below		do	4	Max	.66	.14	.50	860	9	12	0	0	37	32	460.0	2.24	6.50	35	7.9	22.0
				Min	.01	.01	0	10	0	0	0	0	0	0	460.0	.77	4.74	22	7.3	3.0

TABLE 7.—*Guyandot River*

Station	Mile	Date 1939	No. of Samp.	Volume				Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
					T	I	II													
				Ave	0.37	0.11	0.05	53	15	67	2	25	6	2	2,087	2.40	6.25	41	7.3	22
Huntington		June 14 to Nov. 27	16	Max	1.4	.65	.24	316	108	260	8	180	40	8	11,000	7.64	10.68	210	7.5	28.5
				Min	.06	0	0	0	0	4	0	0	0	0	91	.90	.08	5	6.7	7
Chapmanville	69	Dec. 1	1		.36	.02	0	212	4	80	0	0	0	12	30	1.57	10.97	5	7.4	8
Henlawson	76.8	Nov. 28	1		.07	.04	0	392	4	8	0	4	0	0	43	2.38	7.49	32	7.1	8
Logan:																				
Above		Nov. 30	1		.08	.02	0	1,156	0	0	0	0	8	0	75	1.58	12.63	3	7.6	4.5
Below	81.4	Nov. 28	1		.08	.08	0	1,008	20	0	0	0	0	0	91	1.86	8.11	20	7.1	9
Man:																				
Above		Nov. 27	1		.11	.11	0	1,580	0	0	0	4	0	0	3.6	1.96	13.31	8	7.9	5.5
Below		do	1		.23	.22	0	718	0	8	0	72	0	0	7.2	2.96	13.69	2	7.9	6.5
Gilbert	111	Oct. 10	1		.02	.02	0	88	0	0	0	4	0	0					7.6	24
Pineville, below	143	Nov. 13	1		.02	.02	0	0	0	0	0	36	0	4	430	3.20	10.89	5	7.7	3.5
Itman	153.6	do	1		.42	.42	0	0	2	1	0	630	0	0	460	4.51	10.59	2	7.7	2.5
Mullens:																				
Above	157.6	do	1		.24	.24	0	0	0	0	0	96	0	0		4.51	10.59	2	7.7	3
Below	156.0	do	1		.01	0	0	4	4	0	0	0	0	0	43	3.64	9.28	7	7.7	3

TABLE 8.—*Kanawha River*

Station	Mile	Date 1939	No. of Samp.		Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. coli	B. O. D.	D. O.	Tby.	pH	Temp.
Point Pleasant	0.6	Aug. 10 to Nov. 27	7	Ave.	0.68	0.19	0.29	55	182	61	0	278	6	6	1.6	0.78	7.34	7	7.3	18.1
				Max.	3.7	1.0	2.0	108	1,112	244	4	864	36	24	4.3	.89	8.53	12	7.6	27
				Min.	.07	0	0	0	4	0	0	0	0	0	.4	.60	6.24	4	6.9	5
Buffalo	21.8	July 6	1		.60	.42	.02	32	460	108	0	8	0	4						
Winfield	31.1	Aug. 10	1		1.1	.15	.84	112	160	52	0	4	12	40					6.8	26
St. Albans, below	46.2	July 4	1		1.1	0.3	0.5	36	0	216	0	36	20	0					6.9	26
Cheylan	73.7	do	1		.03	.01	0	0	0	28	0	8	8	0					7.1	29
Montgomery	85.6	do	1		.15	0	0	0	0	60	0	0	0	0					7.1	

TABLE 9.—*Monongahela River*

Station	Mile	Date, 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.
Dam No. 2	11	Aug. 19	0.25	0	0	0	0	290	0	0	0	0	0.91	0.65	5.38	3.5	19
Dam No. 4	41	do	.60	0	0	0	0	780	0	0	0	0	.73	.85	7.21	3.3	26
Dam No. 5	56	do	.38	0	0	0	0	472	0	0	0	0	2.1	.54	7.30	3.7	26
Dam No. 6	68	do	.02	.02	0	5	5	0	5	85	0	0	.36	.33	7.18	3.3	26.5
Dam No. 7	84	do	.30	.02	.06	0	0	275	0	5	5	0	.36	.66	7.52	3.4	26
Dam No. 8	90	do	.22	0	0	0	0	280	0	0	0	0	.36	.52	7.33	3.3	26.5
TRIBUTARIES																	
TEN MILE CREEK																	
Mariana:																	
Above		Aug. 21	.84	.23	.42	20	240	30	0	10	380	0	23	1.19	6.67	7.6	20.5
Below		do	1.3	.45	.22	40	285	65	0	85	250	40	1,100	2.95	6.66	7.5	20.5
Waynesburg:																	
Below		do	1.9	1.2	.27	55	875	40	40	2,015	90	15	110,000	9.18	.44	7.4	22
Above		do	18.1	.74	.96	135	15	40	5	1,395	320	4,825	93	1.59	5.97	7.6	20.5
PIGEON CREEK																	
Bentleyville:																	
North Fork		do	.04	0	0	0	0	5	0	0	15	0	3.6	.47	7.84	6.6	15
At		do	5.5	1.4	3.1	175	135	135	0	845	470	10	1,100	2.49	8.35	7.6	17.5
Below		do	3.3	2.0	.85	15	115	35	5	1,520	220	10	240	1.91	8.67	7.5	15.5
Cokeburg		do	2.8	2.2	.45	0	35	0	0	745	215	0	240	2.03	8.58	7.6	17.0
Ellsworth		do	.71	.28	.12	5	40	25	0	125	30	10	9.1	1.85	4.37	7.5	18.5
Youghiogheny River, McKeesport		Aug. 19	1.1	0	1.1	0	0	0	0	0	20	95	2.3	1.43	6.18	3.5	25

TABLE 10.—*Allegheny River*

Station	Mile	Date, 1940	Volume			Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.
			T	I	II												
Dam No. 2	6	Aug. 20	0.06	0.03	0	0	0	30	0	10	0	0	2,400	1.54	6.82	6.6	27
Dam No. 3	14	do	3.2	3.2	0	0	0	0	0	49	0	0	.36	.78	6.80	4.4	28
Dam No. 4	24	do	0	0	0	0	0	0	0	0	0	0	.36	.45	7.00	4.3	25.5
Mosgrove	50	Aug. 6	2.1	1.8	.09	20	0	65	0	175	5	0					27
Dam No. 8	52	Aug. 20	.64	.39	.06	25	15	70	5	145	10	5	3.6	1.42	8.10	7.4	25.5
East Brady	70	Aug. 2	2.2	2.0	.19	0	0	55	0	80	6	6			9.67	7.4	27
Parkers Landing	83	Aug. 5	.64	.62	0	0	0	55	0	60	0	0			10.13	7.3	27
Kennerville	110	do	.12	.09	0	0	0	18	6	30	0	0					27
Tionesta, below	150	Aug. 1	1.6	1.0	.06	40	0	150	15	360	15	5					
TRIBUTARIES																	
STONY CREEK																	
Hooverville, above		July 17	.37	.35	0	0	0	5	0	115	0	0	110	.57	8.95	5.2	18
Holsopple, below		do	.09	.02	0	18	0	6	0	6	0	6	3.6	.36	8.71	4.7	19.5
KISKIMINETAS RIVER																	
Freeport		Aug. 20	.57	.07	0	10	0	50	5	175	10	25	3.6	1.56	7.46	7.4	25
Red Bank River		Aug. 6	.15	.11	0	144	0	16	0	48	0	24					
CLARION RIVER																	
Cooksburg		Aug. 3	1.6	1.3	.10	8	0	48	8	144	0	16					24

TABLE 11.—*Muskingum River*

Station	Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.	Tby.
Dam No. 1	0.2	June 28	0.48	0.10	0	5	00	45	0	85	5	5					22.5	
Do	.2	July 10	1.2	.09	0	70	15	225	0	250	25	10					23.5	
Do	.2	July 15	4.5	2.1	1.4	215	40	210	25	405	30	25						
Beverly, above	24	Aug. 8	.59	.55	0	35	0	59	6	145	6	0					29	
Stockport	39	July 19	5.1	3.4	.01	295	50	250	0	1,230	30	35						
McConnelsville	49	do	6.8	4.0	.76	370	60	395	0	840	50	50						
Above	50	Aug. 8	1.4	.50	.55	810	35	150	5	170	15	25			11.39	7.3	28	
Gaysport	61	July 19	7.2	3.9	.65	270	170	740	0	945	95	261						
Duncan Falls	67	May 7	.14	.13	0	66	15	6	0	560	0	0	9.1	1.94	9.79	7.5	16	38
Do	67	July 19	10.1	4.6	3.0	445	215	680	0	735	105	45						
Do	67	Aug. 9	2.5	1.1	.41	380	25	375	15	445	55	20					27	
Zanesville	70	May 7	.45	.44	0	176	4	4	0	1,452	0	0	3.6	2.15	9.84	7.4	15.5	
Below	70	June 7	1.9	1.8	0	170	24	24	0	3,808	8	8					15.5	
Zanesville	75	July 17	9.8	3.8	.66	590	115	790	5	440	60	25						
Below	70	July 19	5.3	1.3	1.2	845	115	795	10	765	70	30				7.5	14.5	
Dam No. 11	84	May 9	1.7	1.6	0	212	0	24	0	600	4	0	4.3	1.75	8.31	7.5	14.5	
Dresden:																		
Above	91	Apr. 30	.25	.15	19	105	0	5	0	10	5	0	3.6	.82	9.88	7.6	15.5	
Below	91	do	1.0	.94	0	165	0	20	0	15	0	0	36	2.79	9.78	7.6	15	115
Coshocton, below	110	May 8	.28	.23	0	232	4	16	0	72	0	4		1.72	8.55	7.5	15.5	32
TRIBUTARIES																		
TUSCARAWAS RIVER																		
Coshocton, above	115	do	.17	.10	0	124	8	16	4	8	4	0					17.5	
West Lafayette, above	120	do	.03	.01	0	36	4	8	0	4	0	0	46	2.29	8.41	7.4	18.5	
Newcomerstown:																		
Below	125	May 18	.14	.4	0	276	4	12	0	220	12	0	93	1.43	8.88	7.4	18.5	
Above	135	May 10	.23	.2	0	240	12	12	0	28	4	0	24	1.17	8.39	7.2	18.5	
New Philadelphia, below	160	May 23	6.4	6.1	.20	44	4	20	4	3,144	20	0	240	1.81	8.90	7.5	19.5	
Dover, above	170	do	4.6	4.5	.05	278	8	16	0	2,500	32	0	93	2.00	9.26	7.8	19	
Barberton, above	225	May 22	1.2	.70	.07	968	52	272	8	368	76	16	1,100	7.29	5.75	8.4	22	
Jonathon Creek		June 10	.30	.16	.10	4	4	40	0	556	8	0				7.7	26	
Mohican River		July 19	5.4	2.4	1.08	8	0	1,200	80	130	226	88				7.9	27	
Killbuck River, 5 miles above mouth		do	1.8	.94	.77	0	70	10	5	195	85	0						
LICKING RIVER																		
Newark:																		
Below		May 1	.20	.19	0	4	0	16		160	0	0	240	3.20	8.34	7.6	15	
Above		May 2	1.1	.07	0	55	15	15		255	5	0	4.3	2.78	9.40	7.7	10.5	
Utica:																		
Below		Apr. 30	.31	.26	0	4	0	0		52	0	4	430	1.73	9.65	7.7	15	
1.5 miles above		do	2.5	2.5	0	15	0	0		100	0	0	9.3	1.20	9.80	7.8	14.5	
At		do	.29	.24	0	36	8	12		48	0	0	15	1.40	9.5	7.8	14.5	

LICKING RIVER TRIBUTARY																		
RACCOON CREEK																		
Johnson:																		
Above	-------	do	1.9	1.9	0	0	-------	0	-------	64	0	0	9.3	1.23	9.36	7.7	13	-------
Below	-------	do	1.0	1.0	0	0	-------	8	-------	92	0	0	3.6	1.18	9.68	7.7	13.5	-------
Granville:																		
Above	-------	do	1.25	1.2	.05	0	-------	0	-------	60	4	0	4.3	1.15	8.55	7.6	14	-------
Below	-------	do	.66	.66	0	16	-------	0	-------	72	0	0	150	2.65	9.49	7.7	13	-------

TABLE 12.—*Hocking River*

Station	Mile	Date, 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.
Hockingport	0.1	June 27	0.48	0.14	0.10	30	110	55	0	50	20	5	7.3	0.87	7.83	7.2	22
Do	.1	July 11	4.9	.81	.44	385	5	958	5	250	50	10	0	2.06	9.15	7.4	26.5
Do	.1	Aug. 14	6.2	1.3	1.9	18	12	171	1,015	561	48	61	9.3	1.83	7.21	7.7	28
Coolville	5	Aug. 17	.71	.28	.11	102	12	262	89	87	18	6			8.41	8.0	28
Guysville	20	do	3.6	1.5	1.6	150	6	139	24	90	281	0			9.0	7.9	27.5
Athens, below	36	June 20	2.1	1.1	.37	25	0	140	15	105	65	0			5.91	7.6	25
Sunday Creek, below	42	Aug. 17	.62	.26	.06	97	200	137	6	18	12	6			7.22	7.1	27
Nelsonville, below	50	Aug. 16	3.3	.69	1.9	35	666	132	0	24	244	31			10.04	8.0	26
Nelsonville	50	July 26	.03	.01	.02	28	0	0	2	2	6	0			7.35	7.4	27
Logan, above	70	do	2.6	2.5	.02	0	0	5	10	420	20	0			7.21	7.5	27
TRIBUTARIES																	
Federal Creek	18	June 10	.60	.53	.07	0	0	0	0	104	12	0				7.5	24
Sunday Creek	43	Aug. 16	.02	.02	0	0	0	6	0	6	0	0				3.0	23.5
Do	43	July 23	.91	.83	0	0	10	3	0	15	0	0			6.60	3.1	27.5
Do	43	July 25	0	0	0	5	0	5	0	0	0	0				6.0	
Monday Creek	49	Aug. 16	.09	.09	0	0	0	0	0	30	0	0			7.07	3.2	27
Do						0	0	0	0		0	0					
Do		July 25	.05	.05	0	0	0	5	0	15	0	0				3.8	
Do	50	July 23	.09	.09		0	0	0	0	30	0	0				2.8	
Do	50	July 25	.36	.36	0	0	0	0	0	120	0	0				3.3	
Little Monday Creek	75	June 6	.09	.09	0	0	5	0	0	85	0	0				6.8	26

TABLE 13.—*Little Kanawha River*

Station	Mile	Date, 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	pH	Temp.
Viscose, below	2	Aug. 22	4.6	0	0.34	30	0	90	0	0	170	5	----------	----------	0.33	6.3	26
Do	2	Aug. 23	2.5	0	.15	0	0	55	0	0	60	0	----------	----------	0	6.1	25
Dam No. 1:																	
Below	3.4	---do---	31.0	0	.01	10	0	710	0	0	125	20	----------	----------	2.45	6.3	26.5
Do	3.4	Aug. 22	13.6	.02	.20	0	0	280	0	5	55	35	2.3	1.50	4.45	6.1	24.5
Above	3.5	---do---	19.4	0	0	5	0	450	0	0	25	75	----------	----------	----------	7.2	25
Do	3.5	Aug. 23	1.1	0	.04	0	0	45	0	35	20	5	----------	----------	4.62	7.1	24
Dock 282	5	June 27	.11	.02	0	5	0	15	0	10	5	5	----------	----------	----------	----------	22
Hughes Creek	17	Aug. 22	.31	.06	.04	420	0	125	0	10	25	115	----------	----------	6.40	7.2	23
Elizabeth	25	June 22	1.03	1.03	0	0	0	8	0	16	0	0	----------	----------	----------	----------	22.5
Below	26	Aug. 22	1.6	1.2	.15	50	0	95	0	75	260	160	3.6	1.44	7.40	7.2	26
Creston	48	Aug. 21	.75	0	.44	35	0	170	15	5	30	15	----------	----------	8.20	7.5	26
Grantsville, above	80	---do---	.90	.52	.11	10	0	35	0	10	10	10	----------	----------	8.80	7.5	26
Do	80	---do---	.24	.01	.17	80	0	35	0	0	10	25	----------	----------	7.50	7.4	24
Glenville:																	
Below	101	Aug. 20	1.6	.99	0	165	0	90	10	60	30	0	----------	----------	6.95	7.1	25
Above	103	---do---	1.1	.54	0	155	0	40	5	20	10	10	----------	----------	6.90	7.1	25

TABLE 14.—*Wabash River*

Station	Mile	Date 1940	Volume			Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
			T	I	II													
New Harmony, below	40	Sept. 18	2.3	0.61	0.71	65	0	250	1,920	50	30	60			9.0		8.3	26
New Harmony	52	Sept. 4	1.8	1.0	0	110	5	125	1,785	10	10	75	5.4	5.12	6.90	10	8.1	25
Grayville	65	Sept. 18	1.7	.01	.40	55	0	465	985	15	30	45			9.10		8.2	24
Mount Carmel	92	do	.8	.03	0	25	0	300	75	50	10	5			7.05		8.1	
Patton	102	Sept. 17	2.3	1.0	.01	65	0	600	840	15	10	15			10.10		8.5	25
St. Francisville	115	do	1.15	.06	.01	130	10	465	435	15	0	55	320	6.20	8.75	20	8.3	24
Vincennes	127	Sept. 4	1.9	.29	0	45	0	715	525	105	0	5						
Meron Ferry	165	Sept. 13	4.1	.08	.18	50	0	1,995	765	235	15	20			10.90		8.1	22.5
Do	165	Sept. 27	0.9	.16	0	6	0	863	92	56	12	0	15	3.58	7.55	5	7.9	17
Hutsonville Ferry	172	do	1.5	.04	0	140	0	871	110	12	18	12	15	3.50	7.44	4	7.9	17
Darwin Ferry	190	Aug. 12	4.9	2.8	0	6	6	1,229	137	124	6	6	460	5.80	4.79	5	7.8	27
Do	190	Sept. 27	2.0	.09	.67	237	0	1,335	136	25	6	12	580	3.92	3.91	5	7.7	18
Prairieton	205	Sept. 13	1.6	.24	0	20	0	655	80	85	10	20			3.40		7.7	21.5
Terre Haute:																		
Below	210	do	2.7	.29	0	25	0	1,080	260	135	0	0			3.50		7.7	19
Do	210	Sept. 26	2.5	.01	1.5	165	0	426	104	0	36	18	96,000	10.6	1.45	10	7.6	16.5
Above	220	Sept. 12	3.3	1.3	.06	56	0	860	225	105	15	5			9.60		8.1	19.5
Clinton, above	232	Sept. 25	1.95	1.1	.01	468	43	666	230	436	18	36	7.5	2.86	8.82	15	8.1	17
Hillsdale	238	Aug. 31	14.7	7.2	0	99	118	2,475	48	1,117	12	56						23.5
Montezuma	240	Sept. 12	2.6	1.1	.16	40	5	645	145	175	5	0			8.00		7.9	19
Perrysville	264	Aug. 30	5.6	1.5	.01	99	56	1,614	61	505	6	67						25
Do	264	Sept. 25	3.2	.38	1.9	865	31	1,026	87	130	30	18	23	3.10	8.60	15	8.2	15.5
Covington	269	Sept. 10	1.6	.56	.45	50	0	240	140	240	35	15			6.90		7.7	21
Do	269	Oct. 2	0.6	.40	0	300	31	450	12	111	0	24	13	2.79	10.25	40	8.1	14.5
Covington, above	270	do	0.7	.49	0	448	18	729	6	143	0	6	13	3.09	10.26	40	8.1	14.5
Williamsport	287	do	0.6	.47	0	398	18	324	0	212	12	0	195	4.02	10.78	23	8.1	16
Attica	288	Aug. 29	11.1	2.5	.01	43	111	2,505	149	374	180	62						
Above	289	Oct. 2	2.4	1.9	.10	178	0	714	6	684	18	12	122	3.50	12.12	12	8.2	17
Independence	294	do	4.6	3.35	.07	143	25	1,003	18	160	49	30	1,100	2.76	11.90	12	8.2	18
Lafayette, below	302	Oct. 3	0.9	.51	0	217	0	572	6	160	24	12	670	3.48	9.25	17	8.1	17
Lafayette	312	Aug. 29	3.65	1.6	.10	101	6	1,031	67	493	54	36						25
Lafayette, above	320	do	2.6	1.3	.38	43	18	470	93	506	68	0						24.5
Delphi, above	330	Oct. 1	4.1	3.1	0	710	56	798	6	179	49	6	43	4.64	14.30	50	8.4	18.5
Delphi	331	Sept. 6	58.3	49.1	4.1	30	483	1,819	31	1,323	148	61			9.60		8.2	27
Do	331	Oct. 1	1.7	.85	.06	886	56	579	0	193	61	61	9.1	4.61	11.37	60	8.4	17.5
Pittsburg	332	Aug. 28	12.3	7.95	1.4	65	78	1,417	136	2,122	143	60						
Georgetown	347	Oct. 3	7.9	4.75	1.1	810	31	958	12	1,235	135	66	43	3.95	8.45	45	8.1	16
Logansport, above	353	Sept. 4	11.6	10.3	.69	430	0	295	55	2,590	65	0			14.50		8.2	25
Do	353	Sept. 30	1.6	1.1	.41	265	50	49	0	275	60	0	93	2.92	11.76	15	8.3	17.5
Logansport	355	Sept. 4	12.3	11.4	.43	1,390	0	195	5	458	70	0			10.50		8.2	26
Do	356	Aug. 27	2.35	.05	.19	50	60	813	155	90	35	15			11.50		8.2	20.5
Logansport, above	357	Sept. 4	2.6	.36	.49	435	0	850	140	270	75	0			11.40		8.2	25
Do	357	Sept. 30	5.4	2.1	1.2	692	81	643	67	596	192	80	3.6	8.80	13.30	100	8.4	16.5

Peru:																		
Below	370	Aug. 1	14.55	13.25	.43	12	0	332	6	3,478	96	6	43	3.41	6.98	90	8.1	24.5
Do	370	Aug. 27	10.9	5.7	2.5	94	264	1,053	43	1,781	318	31						
Do	370	Sept. 3	2.9	.11	.35	360	0	1,305	180	300	65	10						
Above	375	Aug. 1	18.5	16.55	1.1	0	0	322	25	4,161	260	6	7.3	3.32	5.50	150	7.9	23.5
Do	375	Sept. 3	3.6	.24	1.6	125	0	740	170	130	185	20			12.00		8.2	25
Wabash:																		
Below	386	Aug. 2	28.8	24.5	2.85	50	43	560	80	6,257	286	55	930	.627	6.30	45	7.7	23.5
Above	390	do	14.6	9.1	1.7	6	8	927	62	2,466	153	49	.91	3.10	6.35	85	8.0	23.5
TRIBUTARIES																		
TIPPECANOE RIVER																		
Springboro	8	Sept. 6	.66	.27	0	0	0	179	0	281	0	7			9.50		8.2	26
Do	8	Aug. 28	1.8	.34	.47	0	48	350	210	230	30	5						
	8	Sept. 7	.58	.15	.05	20	0	110	10	275	15	5			9.25		8.2	25
Monticello	24	Aug. 30	5.80	.56	2.6	87	181	460	205	659	347							23.5
Buffalo	38	Aug. 28	1.4	.45	.04	12	43	232	6	156	6	0						
Do	38	Sept. 7	.59	.06	.02	15	0	175	5	35	10	0			7.20		8.1	24.5
Pulaski	48	Aug. 28	.97	.39	.03	40	48	210	0	130	20	0						
LITTLE WABASH RIVER																		
Emma	25	Sept. 16	5.9	.13	1.4	884	0	215	70	35	320	75			12.45		8.3	23
Carmi:																		
Below	41	Sept. 4	.91	.56	.12	64	0	12	4	248	16	64						22
At	42	Sept. 18	1.2	.09	1.0	35	5	30	5	30	0	5			10.15		8.3	27
Above	43	Sept. 4	11.1	.12	1.0	180	0	3,000	5	50	160	75						22
VERMILLION RIVER																		
Grape Creek	19	Aug. 30	3.6	1.6	13	199	111	227	37	941	123	80						22
Danville:																		
Below sewage	19	Sept. 11	6.6	1.4	4.5	90	0	240	35	480	420	0			1.87		7.8	21
Below	19	Sept. 10	9.0	1.9	6.4	40	0	290	30	725	565	15			2.05		7.7	22.5
Danville	22	Aug. 30	1.4	.63	.20	100	249	204	12	225	90	12						23.5
Do	22	Sept. 11													9.10			25
Danville:																		
Above	20	do	4.9	1.1	3.3	120	0	135	0	480	340	0			3.50		7.9	23
Below	14	Sept. 10	3.0	1.3	.49	35	0	305	35	560	100	0			5.45		7.7	20.5
Middle Fork	74	Aug. 30	1.4	.7	.09	154	181	311	0	0	24	6						24
WHITE RIVER																		
Above mouth	3	Sept. 17	1.6	.27	.44	250	5	195	25	85	45	20	2.3	3.95	8.22		8.2	24
Do	3	Sept. 5	4.4	3.0	.49	265	50	339	159	110	97	49	8.9	3.85	8.05	25	8.1	25
Hazelton, below	15	Sept. 20	1.4	.58	.21	785	0	210	100	15	55	15			9.00		8.2	26
Do	15	Sept. 4	4.3	1.4	2.0	204	0	380	124	124	52	36						23.5
Petersburg, below	47	Sept. 21	1.2	.20	.11	720	5	475	35	70	50	40			8.50		8.1	27
Washington, below	61	Sept. 23	5.6	.94	4.0	965	10	300	50	150	40	125			6.90		8.0	26
Edwardsport	94	do	6.6	2.6	2.7	20	65	535	25	3,160	45	80						

TABLE 14.—*Wabash River*—Continued

Station	Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
Newberry	116	do	12.4	10.2	.34	80	0	847	5	2,570	50	10	-----	-----	11.30	-----	8.4	25
Worthington	143	Sept. 24	30.4	28.5	.15	26	37	661	31	6,887	30	49	43	7.52	7.98	15	7.9	23
Spencer, below	165	do	28.8	24.3	2.3	105	75	1,280	61	6,112	48	61	93	6.76	11.70	15	8.1	23.5
Spencer	168	Sept. 23	34.5	32.6	.37	5	210	890	15	1,618	40	50	-----	-----	15.65	-----	8.3	24
Above	170	Sept. 24	44.3	38.1	1.6	43	289	3,128	61	9,540	67	48	15	5.72	9.40	15	8.1	23
Martinsville:																		
At	194	Sept. 3	7.6	2.9	.91	18	118	1,997	211	3,600	130	0	-----	-----	8.60	-----	8.2	23.5
Below	190	Sept. 10	5.0	2.7	.16	6	93	1,244	0	4,562	18	24	460	5.28	9.72	7	8.2	21.5
Martinsville	194	do	4.2	1.6	.50	6	93	951	42	2,096	42	18	2,400	5.77	9.90	-----	8.1	21.5
Above	200	do	2.7	1.5	.49	0	69	686	12	1,437	24	12	2.3	4.46	10.05	7	8.2	21
Indianapolis:																		
Below	225	Sept. 17	2.0	1.6	.10	6	20	222	0	560	12	0	7.3	7.31	4.45	3	7.7	21
Do	237	do	1.1	.55	.15	0	37	481	0	477	84	0	23	8.33	6.02	8	7.7	24.5
Do	239	do	9.4	1.2	.96	237	493	1,634	12	1,042	102	18	230	8.29	6.30	-----	7.7	25
Above	257	do	11.6	2.8	3.5	206	530	3,014	6	16,575	215	56	9.3	5.02	12.04	35	8.1	17.5
Noblesville:																		
Below	265	Sept. 27	4.4	1.7	.91	54	796	1,539	0	6,942	27	16	-----	-----	8.50	-----	8.1	15
Do	265	Sept. 12	35.7	1.8	31.1	400	1,740	665	0	1,425	1,062	115	4.60	7.97	8.59	-----	8.1	19
Above	271	do	21.1	1.6	17.8	135	1,496	1,093	0	1,145	1,136	24	23	5.70	11.61	23	8.4	18.5
Anderson	297	Aug. 21	4.1	3.0	.1	14	55	294	0	4,882	42	6	390	3.99	5.30	55	8.0	21.5
Muncie:																		
Below	309	do	3.4	.36	1.7	0	0	1,667	0	120	136	24	460,000	22.8	0	-----	7.1	17.5
Do	310	do	.08	.02	0	6	0	200	0	6	0	0	1,100,000	59.6	0	70	6.1	19.5
Above	312	do	3.5	1.3	1.4	50	81	334	0	49	259	49	46	2.22	9.04	65	8.2	21
Winchester, below	338	Aug. 22	5.5	1.4	3.2	62	305	485	0	80	279	68	46,000	8.25	2.87	17	8.0	19
EAST FORK OF WHITE RIVER																		
Above mouth	51	Sept. 21	.48	.11	.10	160	0	90	70	80	35	10	-----	-----	7.75	-----	8.2	24
Shoals	75	Sept. 3	.74	.05	0	40	5	135	40	5	45	60	.91	-----	-----	-----	-----	16
Bedford	93	do	.75	.19	0	260	5	400	70	55	5	10	-----	-----	-----	-----	-----	-----
EEL RIVER (WHITE RIVER)																		
Worthington	-----	Sept. 23	.63	.12	.18	1,730	0	175	45	10	145	20	-----	-----	8.45	-----	8.1	26
PATOKA RIVER																		
Above mouth	-----	Sept. 17	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	8.45	-----	5.0	21
Below Princeton waterworks	-----	Sept. 20	2.5	.57	.17	40	0	805	100	360	65	0	-----	-----	9.20	-----	6.9	23
Above Princeton waterworks	-----	do	.23	.04	.17	555	0	0	0	0	105	5	-----	-----	9.20	-----	6.9	23

OTHER TRIBUTARIES																		
WILD CAT CREEK		Aug. 29	3.9	2.4	.61	286	31	358	53	380	151	25			10.50		8.2	24.5
Near mouth		Sept. 6	2.6	.64	.32	225	0	810	150	50	10	20			10.85		8.6	25
EEL RIVER																		
Spencer Park		Sept. 4	11.6	10.7	.19	310	0	180	5	2,680	30	30			10.49		8.2	24
EMBARRASS RIVER																		
Lawrenceville		Aug. 31	23.8	20.4	2.1	157	75	337	0	2,198	450	27			8.70		8.1	19
Above		Sept. 26	5.9	5.0	.70	145	0	15	5	90	95	20			8.70		8.1	19
Below		do	.89	.01	.82	100	0	95	0	30	180	5			8.95		8.2	25
MISSISINEWA RIVER																		
Mouth		Sept. 3	.48	.08	.39	305	0	5	5	0	40	0			9.25		8.2	23

TABLE 15.—*Tradewater, Saline, and Green Rivers*

Station	Mile	Date 1940	Volume T	Volume I	Volume II	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
TIDEWATER RIVER																		
Providence		Oct. 4	0.11	0.02	0.02	62	0	6	0	12	12	6			9.00		7.7	17
Sturgis		do	.17	.03	.07	31	6	0	0	6	37	12			5.90		7.5	18
SALINE RIVER																		
Gibsonia		Oct. 3	1.3	.74	.02	35	20	10	0	150	85	30			5.85		7.5	19
GREEN RIVER																		
Below Dam 1	9	Oct. 8	.02	.02	0	38	0	0	0	69	0	0	0.91	0.43	8.40	13	7.7	21
Kentucky Highway 54	25	do	.03	.03	0	6	0	6	0	144	0	0			7.05		7.7	22
Kentucky Highway 56	45	Oct. 7	.07	.06	0	25	0	0	0	280	6	0			6.70		7.8	21
Above Dam 2	64	do	.09	.09	0	6	0	0	0	425	0	0			6.50		7.6	21
Below Rough River	70	Oct. 9	.28	.16	.10	106	0	0	0	44	18	0			7.35		7.6	22
Above Rough River	72	do	.05	.04	0	6	0	0	0	310	0	12			7.10		7.6	22
Dam 3	108	Oct. 24	.04	.02	0	25	15	10	0	30	0	0			8.68		7.8	19.5
Dam 4	149	Oct. 22	1.6	0	.50	25	0	12	0	0	12	49			9.15		7.7	18
Mouth of Barren River	150	Oct. 24	.05	.01	0	10	10	10	0	10	0	10						19
Dam 6:																		
Below	180	Oct. 18	.15	.14	0	645	0	5	0	10	5	5		1.22	9.45		7.8	17
Above	182	do	.03	.03	0	234	0	0	0	0	0	2	.23	1.22	8.33	5	7.8	17
Munfordville	212	Oct. 17	.02	.01	0	57	0	0	0	38	0	6	.75	.78	9.90	8	7.7	14
Greensburg	260	Oct. 16	.02	.02	0	18	0	0	0	62	0	0			8.31		7.6	15
Eunice	310	do	.27	.01	0	181	0	6	0	6	75	6			8.78		7.4	17
GREEN RIVER TRIBUTARIES																		
Nolin River	82	Oct. 14	.19	.01	.17	6	0	0	0	44	24	0					7.9	18.5
Do	34	Oct. 11	.51	.51	0	75	0	0	0	5	5	0	4.3	1.14	9.95		7.9	16
Do	83	Oct. 14	.02	.01	0	81	0	0	0	0	6	0			8.85	10	7.9	18.5
Barren River	15	Oct. 22	.23	.02	.05	45	3	6	0	15	6	0	.91	1.08	8.33	10	7.7	17
Do	60	Oct. 19	0	0	0	10	0	0	0	20	0	0	2.3	1.81	6.78	10	7.7	16
Do	75	Sept. 29	.04	.04	0	25	0	6	0	144	0	0						
Do	90	Oct. 19	.02	.02	0	206	6	0	0	6		0	2.3	.10	8.90		7.7	14.5
Mud River	34	Oct. 24	.67	.58	0	15	80	35	0	5	0	5		1.20	2.64		7.3	14
Rough River	1	Oct. 9	.09	.01	0	69	0	6	0	50	12	25			7.20		7.6	21
Do	30	do	.06	0	.04	50	0	0	0	0	24	0			6.10		7.1	17
Do	80	Oct. 11	.31	.04	.19	301	0	12	0	6	42	6			6.15		7.5	16
Do	120	do	.03	.02	0	63	0	0	0	12	0	12			8.70		7.8	14
Pond River	15	Oct. 5	.97	.10	.72	1,383	0	0	0	5	130	15			8.25	8	7.2	16.5
Do	25	do	1.3	.14	.83	1,100	5	10	0	20	234	15			5.60	8	7.0	16
Pond River, at mouth	0	do	.66	.54	.09	55	0	0	0	35	15	15					7.7	23

TABLE 16.—*Cumberland River*

Station	Mile	Date 1940	Volume			Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	D. O.	pH	Temp.
			T	I	II										
Dam F	43	Nov. 18	0.06	0.04	0	16	35	5	0	20	0	6	10.97	7.7	11
Dam E	66	do	.10	.09	0	5	90	10	0	70	0	20	10.57	7.6	10
Dam D	88	Nov. 15	.12	.08	0	15	90	20	0	0	0	0	10.35	7.6	11
Dam C	108	do	.08	.05	0	5	0	10	0	15	0	5	9.35	7.6	11
Dam B	140	Nov. 6	1.0	.01	0	0	0	208	0	4	4	8	8.30	6.5	17
Dam A	150	Nov. 4	4.7	.01	0	0	5	590	0	60	5	35	6.29	7.5	16.5
State Pen	182	Oct. 30	1.1	.07	0	5	75	265	0	20	5	5	3.21	7.3	20
Dam 1:															
Below	187.5	Nov. 4	.32	.14	0	0	140	50	5	5	15	5	5.99	7.3	19
Do	187.5	Oct. 30	.67	.06	.18	-------	36	124	0	64	8	72	1.73	7.3	22
At	188	do	.10	.06	0	10	30	10	0	15	0	0	.67	7.8	21
Below Nashville	189	do	8.2	1.1	5.0	40	210	615	0	45	65	660	2.66	7.1	18
Dam 2	201	Nov. 1	.73	.44	0	8	44	112	0	12	28	0	6.10	7.3	18
Below Dam 3	217.5	Nov. 7	.10	.04	0	35	30	50	0	30	0	20	9.30	7.9	16
Dam 3	218	Nov. 1	.19	.03	0	0	24	56	0	8	0	20	9.65	7.9	18
Dam 4	237	Nov. 7	.42	.07	0	10	70	130	5	10	5	0	-------	7.7	16.5
Dam 5	264	Nov. 12	.33	.06	0	25	35	15	5	90	0	0	9.70	7.8	14.5
Dam 6	281	Nov. 13	.04	.02	0	80	35	30	0	5	5	0	10.15	7.7	13.5
Dam 8	317	do	.06	.02	0	205	10	10	5	0	0	0	10.05	7.8	14
TRIBUTARIES															
Harpeth River	152	Nov. 4	.07	.05	0	5	0	5	0	15	0	5	8.30	7.7	14.5
Stones River	205	Oct. 29	.72	.10	0	88	76	60	0	8	4	8	8.05	7.7	18
Caney Fork	309	Nov. 13	.13	.10	0	175	5	15	0	40	0	0	10.90	7.7	12

TABLE 17.—*Ohio River*

Station	Mile	Date	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
Emsworth Dam	6	Oct. 10, 1940	0.09	0	0	75	0	0	0	5	0.46	0.76	2.85	9	5.8	16.5
Do	6	Oct. 22, 1940	.02	10	0	45	0	0	0	0	.20	1.22	3.07	8	5.3	12.5
Do	13.5	Oct. 10, 1940	.34	5	0	45	0	60	0	0	15	.82	7.95	9	5.9	16.5
Do	13.5	Oct. 22, 1940	.24	10	0	40	0	120	10	5	11	1.81	7.53	6	5.3	13.5
Montgomery Dam	31.7	Oct. 10, 1940	.13	40	20	90	0	5	0	0	11	1.02	8.07	6	6.2	17.5
Do	31.7	Oct. 22, 1940	.08	0	0	105	0	35	0	5	7.3	.72	8.21	7	5.2	14.0
Dam No. 7	36.5	Oct. 10, 1940	.16	25	0	125	0	0	5	0	11	1.23	10.10	7	6.4	17.5
Do	36.5	Oct. 22, 1940	.38	5	0	85	0	0	5	0	24	.85	10.16	8	5.3	14.0
Dam No. 8	46.4	Oct. 11, 1940	.11	20	0	70	0	0	5	0	4.6	.65	9.59	3	6.0	17.0
Do	46.4	Oct. 21, 1940	.24	25	0	30	0	75	5	5	161	1.06	9.79	7	5.6	13.5
Dam No. 9	56.1	Oct. 11, 1940	.30	0	0	205	0	5	10	0	0	.63	9.46	3	5.9	16.0
Do	56.1	Oct. 21, 1940	.43	10	0	40	0	10	5	0	46	1.17	9.71	6	5.6	13.0
Dam No. 10	66	Oct. 11, 1940	.77	0	0	160	0	15	0	10	.1	.84	9.22	3	4.7	17.5
Do	66	Oct. 21, 1940	.50	265	0	68	0	40	5	0	59	1.59	9.65	8	5.4	14.5
Dam No. 11	77	Oct. 11, 1940	.36	0	0	200	0	10	0	0	4.6	1.39	7.72	3	4.7	17.5
Do	77	Oct. 21, 1940	.27	155	45	40	0	0	5	0	4.3	2.25	8.39	7	5.2	13.5
Dam No. 12	87.5	Oct. 11, 1940	.09	0	0	210	0	0	0	0	.4	1.22	8.10	4	4.7	16.5
Do	87.5	Oct. 21, 1940	.03	60	0	70	0	0	0	0	4.6	1.36	8.40	10	5.0	12.5
Dam No. 13	96	Oct. 11, 1940	.07	5	0	960	0	0	0	0	2.4	1.80	8.70	4	4.7	16.5
Do	96	Oct. 21, 1940	.42	0	0	220	10	25	0	0	4.6	1.07	9.26	6	4.9	12.5
Dam No. 14	114	June 28, 1940	.39	30	0	130	0	135	0	0	4.6	.90	8.43	20	7.8	22.5
Do	114	July 10, 1940	.55	50	0	100	0	50	0	10	46	.63	8.82	10	6.6	24
Do	114	July 16, 1940	.39	120	0	140	0	0	0	0	15	.47	8.49	8	6.7	24
Do	114	July 30, 1940	.40	135	0	110	0	20	0	20	24	1.04	7.68	9	6.4	28
Do	114	Aug. 27, 1940	1.80	0	0	1,760	0	10	0	0	.4	1.19	7.89	4	4.1	24
Do	114	Sept. 10, 1940	.23	0	0	250	0	5	0	5	.2	.74	7.32	5	4.3	21
Dam No. 15	129	June 28, 1940	.34	5	0	65	0	10	5	5	23	.71	8.38	17	7.2	22
Do	129	June 30, 1940	.23	85	0	55	0	85	5	0	----	----	----	----	----	28
Do	129	July 10, 1940	.83	5	0	55	0	25	0	5	9.3	.57	9.21	9	6.6	24
Do	129	Aug. 15, 1940	.07	0	0	85	0	0	0	0	11	.84	6.98	4	4.9	25
Do	129	Aug. 27, 1940	0	5	0	0	0	0	0	0	.9	.88	7.65	4	4.2	23
Do	129	Sept. 10, 1940	.10	0	0	75	0	5	5	0	.4	.40	7.89	6	4.3	22.5
Dam No. 16	146.5	June 28, 1940	.25	10	0	30	0	20	10	0	35	.68	8.31	70	7.1	22.0
Do	146.5	July 10, 1940	.10	35	0	200	0	65	5	0	2.3	.70	9.29	9	6.7	23.0
Do	146.5	July 16, 1940	.33	355	0	160	0	15	0	0	24	.82	9.04	8	6.8	23.5
Do	146.5	July 30, 1940	.23	30	0	105	0	28	0	0	4.3	.82	7.73	11	6.4	28.5
Do	146.5	Aug. 27, 1940	.72	0	0	20	0	10	0	0	2.3	1.61	8.03	3	4.6	23.0
Do	146.5	Sept. 10, 1940	.20	0	0	235	0	0	0	0	.4	1.16	9.12	5	4.4	22.0
Dam No. 17	167.5	June 28, 1940	.32	10	0	60	0	30	0	5	240	.90	8.31	27	7.0	22.5
Do	167.5	July 10, 1940	1.20	100	0	100	0	95	10	0	0	1.11	9.15	11	7.0	23.0
Do	167.5	July 16, 1940	.77	480	0	105	0	70	10	5	4.3	1.10	8.87	10	7.0	23.5
Do	167.5	July 30, 1940	.35	230	0	290	0	20	0	5	9.3	1.32	7.87	11	6.7	29.0
Do	167.5	Aug. 15, 1940	.20	0	0	90	----	90	0	5	.9	1.45	6.85	4	6.0	27.5
Do	167.5	Aug. 27, 1940	1.40	5	0	10	0	15	0	10	2.3	.72	8.63	2	4.8	24.0
Do	167.5	Sept. 10, 1940	.33	0	0	390	0	0	0	0	.2	.70	9.12	7	4.9	23.0

Dam No. 18	180	June 27, 1940	1.3	50	10	150	5	160	20	25	15	1.38	8.59	70	7.1	22.0
Do	180	July 11, 1940	1.9	125	10	230	30	70	75	5	75	1.28	9.09	16	7.0	24.5
Do	180	July 17, 1940	4.0	480	20	225	30	395	19	20	2.3	1.32	8.62	10	7.3	24.0
Do	180	July 29, 1940	1.7	100	0	95	10	395	20	20	23	1.77	7.36	18	7.3	29.5
Do	180	Aug. 14, 1940	1.2	15	0	50	0	185	0	10	9.3	1.25	7.36	3	7.4	28.0
Do	180	Aug. 28, 1940	.40	110	0	55	0	55	15	5	240	3.11	7.47	345	6.9	23.5
Do	180	Sept. 9, 1940	.89	45	0	845	15	240	5	5	24	1.25	8.39	14	6.3	23.5
Dam No. 19	192	June 27, 1940	.61	5	0	100	0	20	15	10	91	1.58	8.46	59	7.3	23.0
Do	192	July 11, 1940	3.5	80	0	215	20	305	10	0	9.3	1.22	8.89	14	6.9	23.0
Do	192	July 17, 1940	2.3	375	0	70	0	60	0	20	24	5.43	8.43	8	7.5	24.0
Do	192	July 29, 1940	1.2	80	0	65	0	255	5	20	93	1.57	7.61	40	7.3	30.0
Do	192	Aug. 14, 1940	.86	25	20	65	0	360	10	15	46	1.26	7.11	5	7.5	28.5
Do	192	Aug. 26, 1940	.97	10	0	25	0	75	0	5	21	1.13	7.52	4	7.1	23.5
Do	192	Sept. 9, 1940	.67	30	0	590	35	295	5	10	93	1.50	8.10	14	6.8	23.5
Dam No. 20	202.5	June 27, 1940	1.6	16	0	204	24	112	24	8	43	1.36	8.30	48	7.3	23.0
Do	202.5	July 11, 1940	3.7	105	0	305	0	280	10	0	121	1.05	8.92	16	6.9	24.0
Do	202.5	July 17, 1940	2.9	252	15	60	5	170	15	15	110	1.41	8.56	12	7.2	23.5
Do	202.5	July 29, 1940	.60	25	10	115	5	375	0	10	93	1.77	7.51	49	7.2	29.0
Do	202.5	Aug. 26, 1940	.67	0	0	45	0	185	0	0	2.3	1.05	7.72	4	7.1	24.0
Do	202.5	Sept. 9, 1940	.16	15	0	25	0	185	0	0	11	1.78	8.60	12	6.8	23.5
Dam No. 21	214.5	June 27, 1940	.78	15	5	190	0	60	15	0	75	1.51	8.33	48	7.2	22
Do	214.5	July 11, 1940	1.0	50	0	135	0	185	0	0	46	1.15	9.02	17	6.9	24
Do	214.5	July 17, 1940	2.6	630	5	35	5	277	15	0	15	1.25	8.43	12	7.2	23
Do	214.5	Aug. 14, 1940	1.5	5	0	185	0	255	0	5	.9	1.15	7.75	4	7.4	27.5
Do	214.5	Aug. 26, 1940	.83	10	0	15	0	250	0	0	15	1.31	8.03	3	7.1	25
Do	214.5	Sept. 9, 1940	.24	5	0	35	0	160	10	0	24	1.10	8.73	12	6.8	23
Dam No. 22	221	June 27, 1940	.48	10	16	239	0	26	5	0	110	1.45	8.12	84	7.2	23
Do	221	July 11, 1940	2.40	10	0	10	10	115	0	0	15	1.21	8.79	15	6.7	23
Do	221	July 17, 1940	1.00	615	4	28	0	128	9	4	15	.96	8.40	13	7.0	21.5
Do	221	July 29, 1940	.33	65	0	40	0	100	0	5	15	1.22	7.12	77	7.1	27
Do	221	Aug. 14, 1940	1.3	0	0	165	5	335	0	0	.7	1.18	7.82	5	7.4	27
Do	221	Aug. 26, 1940	.81	20	0	110	0	205	5	0	24	1.11	7.89	3	7.1	23
Do	221	Sept. 9, 1940	.55	35	0	200	15	445	0	5	2.3	1.00	8.62	13	6.8	22
Dam No. 23	231.5	June 27, 1940	1.2	5	5	145	0	35	20	0	230	1.45	8.26	62	7.2	23
Do	231.5	July 11, 1940	.06	0	0	5	0	60	0	0	3.9	.85	8.91	16	6.6	24
Do	231.5	July 17, 1940	1.10	765	0	50	10	115	15	10	9.3	1.37	8.57	12	7.1	23.5
Do	231.5	July 29, 1940	.56	35	5	50	5	255	5	10	4.3	1.23	7.34	41	7.1	29
Do	231.5	Aug. 26, 1940	1.40	0	5	115	0	475	0	0	1.5	1.28	8.06	3	7.0	24.5
Do	231.5	Sept. 9, 1940	.72	30	0	125	5	575	5	0	2.3	1.51	9.27	11	6.8	22.5
Dam No. 29	316	June 23, 1939	2.9	16	0	124	16	3,544	8	16	93	1.32	8.63	65	------	26
Do	316	June 29, 1939	.19	4	0	16	4	130	0	4	43	1.60	7.32	85	7.3	26
Do	316	July 7, 1939	.49	4	0	28	0	188	20	4	30	1.93	7.99	------	------	26
Do	316	July 13, 1939	.59	4	16	96	0	40	0	8	91	.48	7.70	------	------	26.5
Do	316	July 21, 1939	.21	0	16	48	0	64	4	0	333	.95	7.89	------	------	25
Do	316	July 27, 1939	.42	36	104	64	36	52	8	4	72	.84	8.27	------	------	26
Do	316	Aug. 4, 1939	.29	16	0	80	0	72	0	0	59	1.09	7.60	------	------	26
Do	316	Aug. 10, 1939	.12	304	28	52	20	64	0	16	95	.76	8.07	------	------	25.5
Do	316	Aug. 18, 1939	4.9	52	24	66	0	1,684	0	20	515	.61	7.55	------	------	27.5
Do	316	Aug. 24, 1939	.37	112	20	36	40	164	4	16	159	.88	7.90	------	------	26.5
Do	316	Sept. 1, 1939	.09	8	36	16	20	12	0	16	310	.90	7.23	6	7.3	26
Do	316	Sept. 6, 1939	.25	52	48	12	0	4	0	20	264	.92	7.27	------	------	25

TABLE 17.—*Ohio River*—Continued

Station	Mile	Date	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
Dam No. 29	316	Sept. 14, 1939	.02	4	12	8	0	4	0	0	69	.70	7.55	-----	-----	26.5
Do	316	Sept. 20, 1939	.08	16	20	8	0	0	0	8	142	.85	7.39	-----	-----	24
Do	316	Sept. 28, 1939	.08	16	4	8	0	4	4	4	76	.92	7.59	-----	-----	23.5
Do	316	Oct. 12, 1939	.43	24	4	140	4	168	0	0	387	.67	8.32	-----	-----	20
Do	316	Oct. 24, 1939	.26	0	4	56	0	8	0	0	283	.61	9.31	-----	-----	16.5
Do	316	Nov. 9, 1939	.30	12	24	108	88	140	0	0	121	1.07	11.34	-----	-----	11
Do	316	Nov. 27, 1939	.11	36	0	60	12	44	0	0	93	.81	12.28	-----	-----	8
Do	316	Dec. 15, 1939	.05	56	0	24	8	48	0	8	18	.93	12.29	-----	-----	6
Do	316	Dec. 28, 1939	.02	4	0	8	0	32	0	0	33	1.05	12.72	-----	-----	3.5
Do	320	June 23, 1939	2.0	3	0	75	5	1,506	3	9	116	1.41	8.26	95	-----	26
Do	320	June 29, 1939	1.5	27	3	45	0	84	3	3	93	1.57	7.43	90	7.2	26
Do	320	July 13, 1939	.42	16	4	80	0	20	4	8	240	.64	7.66	100	7.5	26.5
Do	320	July 21, 1939	.35	12	8	12	0	16	12	16	523	1.02	7.80	200	7.3	25
Do	320	July 27, 1939	.60	0	272	76	12	68	12	16	119	1.11	8.23	24	7.2	26.5
Do	320	Aug. 10, 1939	.47	12	36	100	40	56	4	16	399	.97	8.13	23	7.4	26
Do	320	Aug. 18, 1939	.67	16	32	84	4	100	8	0	312	.63	7.62	45	7.6	27.5
Do	320	Aug. 22, 1939	13.3	52	36	72	8	4,400	4	20	471	1.11	7.54	29	7.4	26
Do	320	Sept. 6, 1939	.41	92	120	28	4	12	4	45	264	1.14	7.12	9	7.3	25.5
Do	320	Sept. 12, 1939	.26	32	72	36	32	20	0	24	129	.86	7.57	2	7.7	25
Do	320	Sept. 14, 1939	.05	56	16	8	0	8	4	0	82	.98	7.37	6	7.6	26.5
Do	320	Sept. 20, 1939	.02	4	0	8	0	36	0	0	81	.68	7.60	4	7.4	23.5
Do	320	Sept. 28, 1939	.39	20	108	64	0	12	8	4	76	1.07	7.90	3	7.7	24.0
Do	320	Oct. 12, 1939	.19	4	0	126	40	56	0	4	125	.77	8.30	4	7.6	21.0
Do	320	Nov. 27, 1939	.21	65	4	44	12	36	0	8	48	.97	12.17	7	7.4	7.5
Do	330	June 14, 1939	.63	99	30	156	0	125	4	36	181	2.42	8.5	23	-----	25
Do	330	June 26, 1939	3.2	60	4	40	0	580	4	0	102	1.16	7.73	27	-----	25.5
Do	330	June 30, 1939	.11	4	0	52	0	28	4	8	240	1.76	6.57	75	7.2	26.5
Do	330	July 14, 1939	.12	0	0	40	8	8	4	0	69	1.07	7.85	-----	-----	25.5
Do	320	July 20, 1939	.51	16	28	28	0	8	0	16	252	1.10	8.08	-----	-----	26
Do	330	July 28, 1939	.35	20	28	104	4	32	8	12	387	1.42	7.98	-----	-----	26
Do	330	Aug. 3, 1939	1.1	28	0	32	8	64	0	4	150	1.24	7.5	-----	-----	26
Do	330	Aug. 11, 1939	.44	240	108	126	40	108	4	4	165	.88	8.31	-----	-----	25.5
Do	330	Aug. 17, 1939	3.8	16	8	32	12	1,216	16	0	115	.54	7.62	-----	-----	27.5
Do	330	Aug. 29, 1939	.47	32	44	8	28	164	0	0	76	.85	7.44	-----	-----	26
Do	330	Aug. 31, 1939	.06	8	40	20	0	8	0	4	199	.81	7.34	-----	-----	25.5
Do	330	Sept. 7, 1939	.41	44	96	12	16	0	0	36	106	.80	7.44	-----	-----	25.5
Do	330	Sept. 15, 1939	1.5	12	24	52	8	32	0	0	391	.73	7.14	-----	-----	26
Do	330	Sept. 21, 1939	.06	0	16	0	4	12	0	0	338	.66	7.30	-----	-----	23
Do	330	Sept. 29, 1939	.04	8	36	0	0	8	0	0	337	.81	7.56	-----	-----	23.5
Do	330	Oct. 13, 1939	.08	44	16	48	0	4	0	4	167	.53	8.46	-----	-----	20
Do	330	Oct. 23, 1939	.26	0	8	44	0	24	4	0	177	.64	9.18	-----	-----	16
Do	330	Nov. 10, 1939	.34	8	28	32	4	104	8	4	67	.91	11.34	-----	-----	10.5
Do	337	June 14, 1939	1.5	184	44	452	0	320	4	8	93	1.96	7.89	20	-----	25
Do	337	June 20, 1939	.60	66	0	48	0	559	3	0	138	1.36	7.58	32	-----	26

Do	337	June 30, 1939	.09	45	0	41	0	48	0	0	195	1.63	6.80	75	7.2	25.5
Do	337	July 14, 1939	.71	16	28	152	0	12	8	8	95	1.17	7.55	85	7.5	26.5
Do	337	July 20, 1939	.40	36	80	52	4	4	0	24	65	1.15	7.68	39	7.2	25.5
Do	337	July 28, 1939	.76	56	144	108	20	82	4	16	74	1.41	7.96	22	7.3	26.5
Do	337	Aug. 3, 1939	1.3	36	0	56	8	104	16	12	161	1.29	6.87	85	7.1	26
Do	337	Aug. 11, 1939	.42	146	260	98	64	56	20	40	157	1.10	7.93	13	7.4	25.5
Do	337	Aug. 17, 1939	4.5	40	36	84	8	1,436	8	8	73	.86	7.29	45	7.3	27
Do	337	Aug. 29, 1939	.33	72	36	68	40	76	0	8	27	.95	7.29	4	7.2	26
Do	337	Aug. 31, 1939	.10	8	52	28	4	88	0	8	60	.89	7.02	5	7.2	25.5
Do	337	Sept. 15, 1939	.06	30	8	16	4	24	0	0	50	.76	7.30	5	7.5	26
Do	337	Sept. 21, 1939	.85	0	30	36	0	12	4	8	31	1.01	7.20	7	7.2	23
Do	337	Sept. 29, 1939	.05	16	4	28	0	68	0	0	52	.67	7.55	3	7.8	23
Do	337	Oct. 13, 1939	.03	12	28	0	0	0	0	0	38	1.01	8.51	5	8.0	20
Do	337	Oct. 23, 1939	.05	0	12	0	8	0	8	16	89	.97	9.14	4	7.7	16.5
Do	337	Nov. 10, 1939	.28	36	88	4	0	168	4	0	76	.72	11.04	7	7.3	10
Do	337	Nov. 24, 1939	.08	68	28	104	0	24	0	0	31	.91	11.68	4	7.5	8.5
Dam No. 33	405	May 1, 1939	.32	8	40	32	0	12	0	4	43	1.49	9.80	47	7.5	13
Do	405	May 9, 1939	37.1	40	184	80	0	5,408	4	52	4.3	1.14	9.89	15	7.7	17.5
Do	405	July 18, 1939	.94	4	0	16	0	4	12	12	9.3	1.99	7.93	53	7.3	25.5
Do	405	July 24, 1939	.34	4	0	76	0	4	4	8	110	2.41	7.15	170	7.3	26
Do	405	Aug. 1, 1939	.50	28	0	40	0	140	12	4	75	1.92	7.06	78	7.2	26.5
Do	405	Aug. 7, 1939	.87	20	16	16	4	284	4	20	9.1	1.33	7.76	27	7.5	27
Do	405	Aug. 15, 1939	.53	236	0	0	0	80	0	12	24	2.64	7.20	65	7.3	27.5
Do	405	Aug. 21, 1939	4.8	4	0	12	4	1,470	0	4	23	2.14	7.83	46	7.3	27
Do	405	Aug. 29, 1939	.46	52	0	56	12	228	0	4	4.6	.90	7.60	15	7.9	26
Do	405	Sept. 12, 1939	.25	0	4	44	40	56	4	0	.23	1.21	7.76	8	7.6	25.5
Do	405	Oct. 30, 1939	.36	28	8	44	8	296	0	4	43	1.42	8.65	38	7.3	15.5
Do	405	Nov. 13, 1939	.56	60	56	108	0	304	4	0	2.3	1.39	11.12	7	7.2	9
Do	405	Nov. 27, 1939	1.2	216	68	270	0	116	4	28	15	1.36	11.70	10	7.3	7.5
Dam No. 34	434	May 1, 1939	.40	8	44	12	0	16	0	12	23	2.92	9.36	51	7.5	13.5
Do	434	May 9, 1939	26.6	28	164	64	0	2,692	0	8	9.3	1.26	10.13	20	7.8	17
Do	434	May 17, 1939	11.9	50	144	64	0	2,032	20	24	4.3	1.26	9.94	8	7.7	18
Do	434	May 25, 1939	3.0	180	16	68	0	948	0	72	2	2.32	9.13	4	7.6	23
Do	434	June 12, 1939	.51	20	0	68	0	326	0	4	22	1.22	7.70	13	7.8	24.5
Do	434	June 20, 1939	.11	81	3	37	5	45	6	0	109	2.17	7.34	108	7.6	26
Do	434	June 26, 1939	.89	17	3	102	0	987	6	17	36	3.58	8.10	97	7.6	25
Do	434	July 18, 1939	.82	0	0	63	0	41	27	12	53	1.15	7.81	48	7.4	25
Do	434	July 24, 1939	.45	0	0	4	8	12	4	12	31	1.65	7.10	190	7.3	25.5
Do	434	Aug. 1, 1939	.43	35	4	80	4	32	16	4	30	1.37	6.66	125	7.3	25.5
Do	434	Aug. 7, 1939	.45	12	0	100	12	188	12	0	20	1.23	7.41	23	7.4	26.5
Do	434	Aug. 21, 1939	1.0	20	0	48	4	456	8	20	264	1.56	7.06	122	7.3	26.5
Do	434	Aug. 29, 1939	.46	24	0	12	0	356	12	0	1	1.60	8.07	15	7.7	25
Do	434	Sept. 12, 1939	.08	4	0	44	8	48	0	4	1	.92	7.90	8	7.6	24.5
Do	434	Sept. 18, 1939	.00	0	0	0	0	0	0	0	1	.86	7.99	7		24.5
Do	434	Oct. 2, 1939	.05	0	0	20	0	12	0	0	7	.91	8.38	13	7.5	20
Do	434	Oct. 10, 1939	.09	8	4	36	0	44	4	0	1	1.05	8.54	11	7.7	21
Do	434	Oct. 30, 1939	.49	8	0	36	12	196	0	0	9	1.44	8.82	64	7.5	14
Do	434	Nov. 13, 1939	.62	204	4	128	0	136	4	12	3	.85	11.28	7	7.2	6
Do	434	Nov. 27, 1939	1.3	326	56	308	8	160	0	4	8	1.08	11.58	12	7.5	9

TABLE 17.—*Ohio River*—Continued

Station	Mile	Date	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
Dam No. 36	461	May 1, 1939	.24	16	16	4	0	24	0	4	3.6	1.18	9.43	56	7.7	12
Do	461	May 9, 1939	32.8	152	172	92	0	2,780	8	8	2.3	1.22	10.27	25	7.8	15
Do	461	May 17, 1939	18.3	12	44	76	0	4,768	0	92	.3	1.70	10.00	5	7.8	17
Do	461	May 23, 1939	38.6	100	52	64	0	3,104	0	92	1	.88	9.48	6	7.4	21
Do	461	June 8, 1939	3.8	244	0	184	0	2,452	28	16	4.3	1.84	7.81	29	8.0	24
Do	461	June 20, 1939	.88	96	0	36	4	180	0	0	150	2.44	7.43	230	7.7	24
Do	461	July 18, 1939	1.5	12	0	132	0	52	36	8	9.3	1.53	8.03	60	7.3	24
Do	461	July 28, 1939	.30	4	0	16	0	52	16	8	23	2.15	7.69	64	7.3	25
Do	461	Aug. 3, 1939	.62	36	16	12	0	88	8	4	30	1.35	6.63	90	7.2	25.5
Do	461	Aug. 7, 1939	.49	4	0	24	4	24	8	4	43	1.08	7.37	23	7.4	26
Do	461	Aug. 21, 1939	1.1	40	0	40	4	152	8	36	43	4.95	7.16	39	7.3	25.5
Do	461	Aug. 29, 1939	.92	16	0	44	0	768	8	4	.93	1.00	8.65	15	8.0	24
Do	461	Sept. 8, 1939	.17	4	0	4	4	168	4	0	2.4	1.60	7.68	10	7.5	26
Do	461	Sept. 12, 1939	.08	4	0	0	28	52	0	0	.43	1.01	7.84	8	7.6	24.5
Do	461	Sept. 18, 1939	1.5	0	0	526	0	24	0	0	.93	.66	8.68	7	-------	24.5
Do	461	Oct. 2, 1939	.11	0	0	64	4	45	0	0	4.3	.83	8.30	14	7.5	17.5
Do	461	Oct. 12, 1939	0	12	0	0	0	0	0	0	.93	.55	8.44	6	7.5	18.5
Do	461	Oct. 30, 1939	.43	148	4	64	8	132	0	0	3.6	1.15	9.48	60	7.5	14.0
Do	461	Nov. 13, 1939	1.3	424	116	98	4	232	16	24	.93	1.30	11.68	8	7.3	9
Do	461	Nov. 27, 1939	2.0	260	4	156	4	140	12	4	3	1.46	12.10	14	7.5	8
Dam No. 37	483	May 4, 1939	1.1	16	88	32	0	112	4	28	240	1.49	8.92	36	7.5	14
Do	483	May 12, 1939	74.7	8	148	105	0	3,164	16	52	2,400	2.51	9.58	12	7.8	19
Do	483	May 18, 1939	7.6	4	27	54	0	1,572	12	3	2,150	2.99	8.97	8	7.9	20
Do	483	May 22, 1939	27.8	156	100	56	0	2,552	8	64	230	4.93	7.35	33	7.6	24
Do	483	June 1, 1939	3.5	308	0	52	0	1,468	12	4	2,300	4.03	6.93	10	7.6	25
Do	483	June 13, 1939	.28	24	16	39	6	250	0	3	430	3.46	7.28	132	7.8	23
Do	483	June 19, 1939	.42	16	0	48	0	240	4	8	300	3.30	6.77	205	9.0	26
Do	483	July 17, 1939	.60	4	0	42	3	30	36	6	390	2.10	7.40	105	7.2	26
Do	483	July 31, 1939	.77	9	18	73	24	45	18	15	400	3.15	6.65	160	7.4	27
Do	483	Aug. 8, 1939	.39	12	0	51	4	132	11	0	24,000	2.64	5.59	50	7.3	27
Do	483	Aug. 13, 1939	2.3	24	24	76	8	120	36	8	93	1.07	3.70	10	7.3	26
Do	483	Aug. 21, 1939	.84	20	4	44	20	284	8	32	2,400	2.30	3.03	15	7.2	23
Do	483	Aug. 28, 1939	1.2	108	0	56	8	994	12	72	313	1.79	6.27	25	7.5	26
Do	483	Sept. 5, 1939	1.7	12	0	27	0	2,044	8	0	91	3.06	5.19	15	7.8	25
Do	483	Sept. 11, 1939	.23	12	0	48	0	88	0	0	373	1.11	2.96	10	7.6	26
Do	483	Sept. 19, 1939	.55	12	0	356	4	136	0	4	240	1.65	5.58	10	7.4	25
Do	483	Sept. 25, 1939	1.5	16	20	644	8	72	0	118	2,400	2.56	2.22	15	7.3	24
Do	483	Oct. 9, 1939	.37	0	0	184	4	64	0	4	13,100	1.88	4.68	7	7.5	22
Do	483	Oct. 27, 1939	.33	64	0	24	0	488	0	0	46,000	1.05	6.54	10	7.5	18
Do	483	Oct. 31, 1939	.74	128	4	136	8	336	8	4	910	1.85	8.84	45	7.4	13
Do	483	Nov. 14, 1939	.49	180	0	92	0	272	4	16	230	1.32	11.33	-------	7.5	9
Do	483	Nov. 30, 1939	.20	404	4	120	68	160	0	0	2,340	3.44	11.08	-------	-------	6

Dam No. 38	503	May 4, 1939	2.0	12	56	72	0	55	4	12	1,533	1.88	8.68	45	7.5	14
Do	503	May 12, 1939	39.8	3	0	108	0	3,768	0	33	1,665	2.59	9.50	15	7.9	17
Do	503	May 18, 1939	16.6	4	52	40	0	3,456	16	20	1,100	2.71	9.17	8	7.9	20
Do	503	May 22, 1939	24.1	116	88	44	0	2,372	4	32	430	2.55	8.67	25	7.8	21.5
Do	503	June 1, 1939	12.4	244	0	168	0	1,198	8	44	230	2.65	7.77	10	7.7	25
Do	503	June 5, 1939	6.0	232	44	112	0	4,432	12	28	443	2.90	7.25	105	7.8	24
Do	503	June 13, 1939	1.4	48	0	268	8	380	4	24	1,100	1.98	6.65	95	8.0	23
Do	503	June 19, 1939	5.1	16	8	20	0	56	0	4	390	2.57	6.08	90	9.0	25
Do	503	Aug. 17, 1939	2.3	16	30	325	0	212	68	28	930	2.46	7.0	84	7.2	25
Do	503	Aug. 31, 1939	.87	6	3	87	3	158	9	12	930	3.20	5.80	265	7.5	26
Do	503	Aug. 8, 1939	.60	40	4	116	8	162	0	0	430	1.72	6.63	70	7.2	26
Do	503	Aug. 14, 1939	2.3	12	4	136	8	200	36	20	430	2.71	6.08	47	7.7	27
Do	503	Aug. 22, 1939	1.2	0	8	56	12	680	16	56	230	1.83	6.33	46	7.5	26
Do	503	Aug. 28, 1939	1.8	20	8	112	12	1,828	56	28	150	2.20	8.20	18	7.6	24.5
Do	503	Sept. 5, 1939	1.7	24	0	104	12	2,556	4	4	36	2.58	6.46	15	7.8	24
Do	503	Sept. 19, 1939	1.2	0	0	172	24	196	8	0	9.3	1.81	4.70	10	7.5	23
Do	503	Sept. 25, 1939	1.8	24	8	1,352	8	80	0	32	240	2.28	6.93	15	7.6	22
Do	503	Oct. 9, 1939	.53	16	12	185	16	340	4	32	240	2.05	5.53	8	7.5	21
Do	503	Oct. 27, 1939	.39	84	0	44	32	348	8	4	1,500	3.02	7.10	7	7.5	17
Do	503	Oct. 31, 1939	1.1	440	8	252	0	266	0	8	430	1.93	8.79	43	7.5	12
Do	503	Nov. 14, 1939	.48	276	8	56	0	172	16	20	2,400	2.48	11.13	12	7.3	8
Do	503	Nov. 30, 1939	2.1	384	12	296	168	136	4	52	2,010	3.37	10.37	0	------	7
Dam No. 39	531	May 4, 1939	1.7	8	104	120	0	160	4	20	240	1.86	8.67	50	7.4	14
Do	531	May 12, 1939	45.1	56	160	132	0	2,988	16	88	430	2.64	9.53	15	7.9	17.5
Do	531	May 16, 1939	49.7	20	164	168	0	6,340	8	96	32	2.65	10.35	8	8.1	18
Do	531	May 26, 1939	26.0	196	0	192	0	3,744	4	60	230	2.44	8.17	5	7.7	24
Do	531	June 9, 1939	5.7	216	0	212	0	4,596	5	24	144	2.34	7.42	144	8.2	27
Do	531	June 15, 1939	.48	28	0	32	0	236	4	8	60	2.03	6.05	62	7.8	23
Do	531	June 23, 1939	.46	72	20	40	0	116	20	8	503	2.86	5.71	215	7.7	26
Do	531	July 21, 1939	.61	0	8	88	0	136	20	4	137	1.98	6.32	112	7.3	28
Do	531	July 27, 1939	.73	8	8	84	0	476	8	16	43	1.90	6.82	112	7.3	28
Do	531	Aug. 4, 1939	.90	28	40	92	56	92	16	4	703	1.15	5.34	89	7.5	26.5
Do	531	Aug. 10, 1939	1.4	64	12	128	36	584	24	4	36	1.10	6.63	22	7.3	26.5
Do	531	Aug. 18, 1939	.34	12	24	80	64	44	12	4	23	1.54	5.58	140	7.3	27.5
Do	531	Aug. 24, 1939	1.1	24	4	70	12	1,324	12	------	43	1.59	7.20	37	7.8	26.5
Do	531	Sept. 1, 1939	2.7	4	4	120	4	2,836	0	0	2	4.21	11.53	15	7.7	25.5
Do	531	Sept. 7, 1939	.52	12	4	120	0	288	0	44	3	2.07	7.87	15	7.9	25.5
Do	531	Sept. 15, 1939	.71	20	8	128	44	1,732	4	4	1	1.57	6.70	8	7.6	26
Do	531	Sept. 21, 1939	1.2	12	12	236	12	284	4	0	1	1.57	6.50	15	7.5	24.5
Do	531	Sept. 29, 1939	3.2	20	60	1,708	16	2,668	0	0	3.6	2.53	10.20	14	8.1	23
Do	531	Oct. 13, 1939	1.6	76	28	280	112	2,152	0	12	7	2.10	8.55	4	7.5	19
Do	531	Oct. 19, 1939	.75	0	0	288	20	0	0	12	16	1.76	8.99	5	7.6	16.5
Do	531	Oct. 27, 1939	1.8	124	24	352	20	92	8	4	24	1.61	8.17	5	7.6	17.5
Do	531	Nov. 2, 1939	6.0	36	16	56	0	108	0	28	34	2.42	8.71	1,960	7.3	13
Do	531	Nov. 16, 1939	.94	1,412	48	168	4	448	12	8	10	2.20	11.40	144	7.3	9
Do	531	Nov. 30, 1939	2.0	320	16	116	0	20	4	48	338	1.85	10.93	------	------	7.5
Do	547.8	Oct. 15, 1940	1.4	15	25	110	0	1,250	5	5	24	3.29	11.58	30	8.4	18.5
Do	559.5	July 29, 1940	.63	5	5	115	10	533	5	0	89	3.26	8.57	13	7.6	30.0
Do	561	Oct. 16, 1940	1.40	30	50	80	0	1,175	0	35	23	3.31	10.90	25	8.4	17.5
Do	562.6	July 29, 1940	.57	0	0	105	0	1,530	0	0	419	1.64	7.64	15	7.6	30.0

TABLE 17.—*Ohio River*—Continued

Station	Mile	Date	Volume Total	Chr.	Cry.	Chl.	Myx.	Bac.	Eug.	Pro.	B. Coli	B. O. D.	D. O.	Tby.	pH	Temp.
Dam No. 39	562.6	Oct. 16, 1940	.66	0	10	100	10	759	5	30	9.3	2.71	11.40	11	8.5	18.0
Do	576.1	July 29, 1940	.80	15	15	105	5	2,165	5	0	142	2.12	7.40	15	7.4	29.5
Do	576.1	Oct. 16, 1940	1.70	24	12	281	------	2,215	0	36	4.3	3.02	10.35	11	8.1	17.5
Do	600	Aug. 9, 1940	1.1	6	0	148	0	1,074	0	0	.91	2.20	8.46	8	8.1	28.5
Do	608.5	Aug. 12, 1940	1.4	0	6	58	0	907	0	6	230	2.39	8.25	12	8.0	28.0
Do	608.5	Oct. 25, 1940	.16	0	6	110	0	285	0	0	460	2.52	7.52	5	7.7	16.0
Do	610	Aug. 12, 1940	1.2	0	0	105	0	1,035	5	0	930	2.26	8.54	11	8.0	29.0
Do	610	Oct. 25, 1940	.55	0	0	45	0	330	0	0	1,100	2.43	7.40	8	7.5	17.0
Do	614	Aug. 12, 1940	3.1	12	0	142	25	3,664	0	0	91	2.74	8.35	8	8.1	28.5
Do	614	Oct. 25, 1940	.32	0	5	65	6	285	0	5	1,100	2.40	7.21	10	7.5	17.5
Do	628	Oct. 23, 1940	.21	0	0	120	0	185	0	0	1,100	2.20	7.51	8	7.5	16.0
Dam No. 43	633	Oct. 23, 1940	.21	5	0	30	0	110	0	0	43	2.10	7.80	5	7.6	16.5
Do	637.1	do	.57	0	25	60	0	610	0	5	60	------	------	------	7.6	16.5
Do	662.9	Aug. 19, 1940	3.9	5	0	135	5	3,610	5	0	110	3.48	6.86	60	7.7	28.0
Do	665	do	3.2	5	0	170	0	4,240	0	0	150	3.47	6.50	62	7.8	28.0
Dam No. 45	703	do	1.6	5	0	65	0	3,115	0	5	75	2.51	5.93	50	7.7	26.0
Do	711.3	Aug. 21, 1940	.27	5	0	15	0	145	0	0	110	2.16	6.35	41	7.5	27.0
Do	722.7	do	3.60	5	0	65	0	2,895	5	10	46	2.09	6.30	38	7.5	27.0
Do	730.6	do	5.10	5	5	155	30	6,300	0	5	46	2.40	6.29	50	7.5	26.5
Dam No. 46	756.5	Sept. 4, 1940	.09	0	0	135	0	350	0	0	24	1.78	6.74	60	7.5	24.0
Do	756.5	Oct. 30, 1940	1.1	5	0	525	10	70	0	0	3.6	2.55	9.33	10	8.1	17.5
Do	760	Sept. 4, 1940	.86	20	0	165	5	5	0	5	110	3.60	7.18	60	7.5	23.5
Do	760	Oct. 30, 1940	1.8	0	0	1,225	0	170	0	30	43	2.35	9.40	8	8.0	16.5
Dam No. 48	777.7	Sept. 4, 1940	1.2	0	0	80	0	550	0	5	24	1.38	7.33	60	7.5	24.0
Do	777.7	Oct. 30, 1940	.56	0	0	1,565	0	75	0	5	23	1.77	8.57	10	7.9	16.5
Do	791	Sept. 4, 1940	.52	0	0	165	0	1,285	0	15	46	2.20	7.31	50	7.6	23.5
Do	791	Nov. 1, 1940	.49	0	0	35	0	220	0	0	43	1.99	9.17	12	7.9	17.5
Do	797.7	Oct. 29, 1940	1.1	0	0	225	0	220	0	5	240	2.76	9.04	13	8.3	18.0
Do	803	Sept. 3, 1940	2.8	0	0	1,650	0	1,165	10	0	75	1.45	7.21	63	7.6	25.5
Do	803	Oct. 19, 1940	.69	0	0	50	10	215	0	5	43	2.43	9.73	13	8.4	18.5
Do	809	Sept. 3, 1940	2.7	30	0	3,050	0	1,270	10	15	150	1.60	7.14	65	7.6	25.5
Do	809	Oct. 29, 1940	.98	0	0	925	5	340	0	0	23	2.78	9.97	13	8.5	18.0
Do	829.1	Sept. 11, 1940	2.0	15	0	255	5	285	5	10	24	1.99	8.54	22	7.7	22.3
Do	829.1	Nov. 16, 1940	6.8	15	0	390	20	2,200	0	60	43	2.18	9.68	13	7.7	14.5
Dam No. 49	845	Sept. 11, 1940	1.3	5	0	240	0	525	15	15	24	1.80	8.36	18	7.7	23.5
Do	845	Nov. 6, 1940	8.0	0	10	210	0	2,295	10	35	46	2.00	9.62	13	7.7	15.0
Do	852.3	Sept. 11, 1940	.98	20	0	1,010	40	540	0	15	15	1.91	9.38	18	7.9	24.0
Do	852.3	Nov. 6, 1940	4.3	0	35	165	0	1,300	0	35	24	2.63	9.87	15	7.5	14.0
Do	864.8	Sept. 10, 1940	1.6	15	0	305	115	600	15	25	9.3	2.98	8.49	18	7.9	24.5
Do	864.8	Nov. 5, 1940	2.5	15	10	490	5	265	0	35	24	1.97	9.50	15	7.8	15.5
Do	870.7	Sept. 10, 1940	.30	10	5	639	136	352	0	5	9.3	1.43	8.46	15	7.9	25.0
Do	870.7	Nov. 5, 1940	1.7	15	0	760	5	4,025	0	15	7.5	1.90	9.40	18	7.8	16.0
Dam No. 50	876.8	Sept. 10, 1940	.26	0	0	300	35	365	10	0	2.3	1.49	8.63	18	8.0	24.5
Do	876.8	Nov. 5, 1940	2.0	10	5	1,290	0	1,400	0	30	9.3	1.74	9.52	15	7.8	17.0
Do	891.6	Sept. 20, 1940	.91	0	0	1,870	60	150	0	0	.73	2.00	9.44	13	8.4	22.5

Do	927.3	do	.96	0	0	1,110	125	105	0	10	2.3	1.65	9.59	12	8.3	24.0
Do	934.3	Sept. 23, 1940	.04	0	0	80	30	5	0	0	2	1.84	8.99	15	7.9	25.0
Do	934.3	Nov. 22, 1940	1.40	15	15	85	0	965	0	10	2.3	8.34	10.40	18	7.7	12.0
Dam No. 52	938.9	Sept. 23, 1940	.09	5	0	75	60	25	0	0	7.5	1.00	8.70	12	7.9	25.0
Do	938.9	Nov. 22, 1940	3.8	30	20	105	0	1,370	0	5	.91	1.86	11.57	18	7.8	11.0
Do	962.6	Sept. 23, 1940	.24	0	0	205	30	25	0	0						26.0
Do	962.6	Nov. 22, 1940	2.0	15	10	100	0	2,424	0	0	9.3	2.31	12.78	20	7.9	10.5
Do	978	Oct. 3, 1940	.62	5	0	225	50	540	0	10	2.3	1.50	9.39	10	8.0	20
Do	978	Nov. 25, 1940	4.2	10	25	170	0	1,845	0	0	2.1	2.45	11.80	125	7.6	9.5
Do	981	Oct. 3, 1940	.34	5	0	60	20	385	0	0	24.0	1.89	9.31	130	7.9	19.5

APPENDIX I

SCIOTO RIVER BIOLOGICAL STUDIES

CONTENTS

Introduction

The lower half of the Scioto River was the object of an intensive study during 30 months from February 1938 to July 1939. During that time the plankton was studied both in the field and in the United States Public Health Service laboratory at Cincinnati at weekly intervals, and the life of the bottom sediments at less frequent intervals. Reference may be had to volume III of the Final Report of the Ohio River Pollution Survey (1) for the hydrography of the stream, population figures, and extent and sources of pollution, also to the drainage basin committee's reports, (2) while Public Health Bulletin 276 (3) gives the detailed hydrobiological findings of the Scioto River studies.

Headwater Streams

The headwaters of the Scioto and Olentangy Rivers, above Columbus, and the headwaters of the five creek basins—Paint, Deer, Darby, Big Walnut, and Little Walnut—are located in areas where population is dense, where industry is concentrated, and where agricultural productivity is high. Almost all of the headwater streams, therefore, receive heavy loads of human, some industrial pollution, and extensive agricultural drainage, and they are consequently well fertilized. Furthermore, the gradients of these streams are slight and, in their lazy flow, time is allowed for ageing of the water. Because of these two factors, biological productivity should be high.

No reliable index of biological productivity for long periods of time is available for the headwaters, but for some stations series of samples covering a few weeks have been examined. For many other points two samples, one above and one below a town or source of possible pollution, have been examined. The general idea gained from these scattered observations is that biological productivity, as far as plankton is concerned, is high in the headwater streams. For example, one of the samples from the Scioto in the vicinity of Kenton, very close to its source, contained 35 species of plankton organisms, some of them in large numbers (October 2, 1939).

In the small headwater streams, radical differences in the plankton above and below a town are sometimes apparent and may be correlated with chemical and

bacterial findings indicative of gross pollution below the town. Paint Creek, above and below Washington Court House, and above and below Greenfield, offers excellent examples. In December 1939, and on into March 1940, the creek above both towns showed large numbers of Chrysophyceae and Cryptophyceae, with abundant dissolved oxygen, low biochemical oxygen demand values, and low coliform counts. Below the towns these conditions were reversed; at times there was no oxygen in some parts of the creek below Washington Court House. At other times or in other stretches of the creek, there were dissolved oxygen values of 10.6 parts per million, along with 10.9 parts per million biochemical oxygen demand and a coliform count per milliliter of 1,000 (most probable number). Cryptophyceae and Chrysophyceae were generally less in numbers below the towns. The flora and fauna were abundant, but principally made up of forms characteristic of activated sludge or a trickling filter—*Sphaerotilus*, *Beggiatoa*, *Chromatium* and not infrequently large numbers of ciliate protozoa. A few species of Euglena were usually present, even if lacking above the towns, but only one species, *Euglena viridis*, was ever abundant; at one time it was so abundant below Washington Court House (however, in a recovery zone) as to constitute a bloom in late December and early January. There was sufficient green plankton in some of the samples to have been a factor in accounting for the high dissolved oxygen values.

Above Columbus Sewage Plant Outfall

Columbus uses much of the river water at times of low flow, but there was always a fair population of plankton organisms at the lower margin of the city, to provide abundant reseeding of the water returned to the river via the sewers and sewage disposal plant. A sampling point located at the lower margin of the city was the uppermost station for routine sampling in the detailed study of the river. It was just below a low head dam and its plankton population generally consisted of organisms that lived principally by photosynthesis and were not dependent on organic matter. That is, clean water organisms were generally predominant at this station.

The Scioto River, from the lower margin of the city to the sewage treatment plant outfall, was frequently sluggish in flow and, besides receiving storm water drainage from the city, also received some raw sewage. It rapidly deteriorated in sanitary quality, and on at least two occasions appeared to be septic about a mile below the uppermost regular sampling point. In effect, the storm drainage and some raw sewage created a zone through which many organisms could not pass, because of oxygen deficiency, H_2S poisoning, and possibly other causes. Only a few species showed a rise between Columbus and Shadeville, the second sampling station, but it was not at all unusual to find empty shells, or dead individuals, of clean water types, at Shadeville or in the intervening stretch and the work sheets for the survey sometimes have notations to that effect.

Objectives

The plankton work of the Scioto River survey had several objectives. One was to show what organisms were to be found in the stream, over a long period of time. It was hoped that this would provide a fairly comprehensive list of river plankton species. Most plankton forms are cosmopolitan and it was not anticipated that extremes of environment, other than the initial badly polluted stretch, would be encountered, so a normal river plankton was envisaged.

A second objective was to determine what, if any effect, Columbus sewage exerted on the plankton, especially with regard to the successive modes of treatment—trickling filter, primary sedimentation and complete treatment.

A third objective was to seek correlations between physico-chemical conditions, coliform counts, and the qualitative and quantitative plankton findings. This last would involve an evaluation of "indicator species," as well as determining the causative factors for peaks in the plankton population.

Results

It is not too much to say that all these aims were achieved, and in addition certain refinements in the technique of handling plankton were evolved, while, as a side issue, a number of new species of algae and protozoa were described.

Species found.—The Scioto yielded 448 groups, genera or species of plankton organisms during the survey. One whole class of algae, the dinoflagellates or Dinophyceae, was very poorly classified as to genera and species. They were few

in number in the Scioto, as in streams generally, but are often abundant in lakes and reservoirs. A number of genera, e. g., *Chlamydomonas*, were not classified to species. Conversely, because of the technique followed, it was possible to identify and count a great many very small organisms, not heretofore usually considered in such surveys. Certainly 448 species or groups of organisms have not heretofore been described from any stream. Subsequent work, including very detailed studies of Tanner's, Laughery, Hogan and Four Mile Creeks; the Cumberland, Duck, Licking, Little Miami and Miami Rivers, all within the Ohio Basin, have confirmed the basic nature of the plankton list. This has also been shown to be substantially correct by less detailed studies of many Ohio Basin streams as well as some studies of Atlantic and Gulf coastal streams, and the Columbia River of the Pacific coast. New species are found elsewhere from time to time, but thus far the great majority of forms found elsewhere has corresponded closely with those found in the Scioto. This even holds true for relative numbers—a species common in the Scioto tends to be common elsewhere, even if the abundance in the Scioto and the second source is in a ratio of 10 to 1 or higher.

Columbus sewage effects.—With regard to the second objective, there was ample evidence as to the effect of the Columbus sewage. There was a large number of species which occurred with some frequency at the lower margin of the city. Some clean-water types occurred here in abundance, but more commonly, numbers of all organisms were low at this station, and they decreased still more, until at Shadeville the low population point for most of the enumerated organisms was reached. The few exceptions were sewage-tolerant forms typified by *Sphaerotilus*. It is to be noted also that some forms appeared at Shadeville which were not found above Shadeville; these, too, were usually sewage-tolerant forms, as certain ciliate protozoa.

A short distance below Shadeville, an increase in the protistan population of the stream began, and this increase reached very high numbers. This was evidence of the fertilizing power of the sewage plant effluent. The types of organisms were those usually found in recovery or clean-water zones; for example, Big Walnut Creek often poured large numbers of *Chrysophyceae* into the river, and these did not die off, as they did in the stretch between the city margin and Shadeville. Evidently the effluent from the sewage treatment plant provided better water than that below the city but above the treatment plant outfall. At Shadeville there were perhaps more organisms typical of carbonaceous oxidation than at any of the other stations, but they soon disappeared and those typical of nitrogenous oxidation, or those dependent on photosynthesis quickly became the bulk of the population. From a biological standpoint, the plant effluent greatly enriched the river, but with material already far along toward stabilization.

In one respect the findings were disappointing. There was no marked difference in the stream flora and fauna traceable to disposal by trickling filter, primary sedimentation, or complete treatment. There were differences in the coliform counts and also chemical differences undoubtedly due to the three types of treatment, but it has long been known that a stream recovers biologically before it recovers otherwise, and such was the case here.

Correlation between plankton findings and other data.—The third objective, correlations between plankton life and other sanitary indices, was not expected to be achieved for all plankton types. But for some species or groups it was well defined. For certain species or groups of species, as shown by the *Chrysophyceae* in figure 1, there was an abrupt drop in population at Shadeville, followed by a gradual rise downstream, with a tendency for the population curve to flatten out or decline in the lower part of the river. Since this figure is based on weekly counts of the organisms present at 13 stations over a river length of 118 miles, and covering 30 consecutive months, such distribution may reasonably be assumed to reflect the response of the organisms to conditions obtaining in the river. The drop at Shadeville is unquestionably a response to the pollution there. It may be a response to some particular phase of the pollution, but certainly to the sewage-plant effluent. As pollution abates downstream, due to dilution, biochemical action, etc., numbers once more increase. Organisms behaving thus over a period of time may therefore be used as indicators of unpolluted water, when present in large numbers. It must be emphasized, however, that evidence should not be adduced from one sample, because a flowing stream is an ever-changing environment, and because the phenomenon of "blooms" of aquatic microorganisms—those sudden appearances of enormous but transient populations—are so little understood.

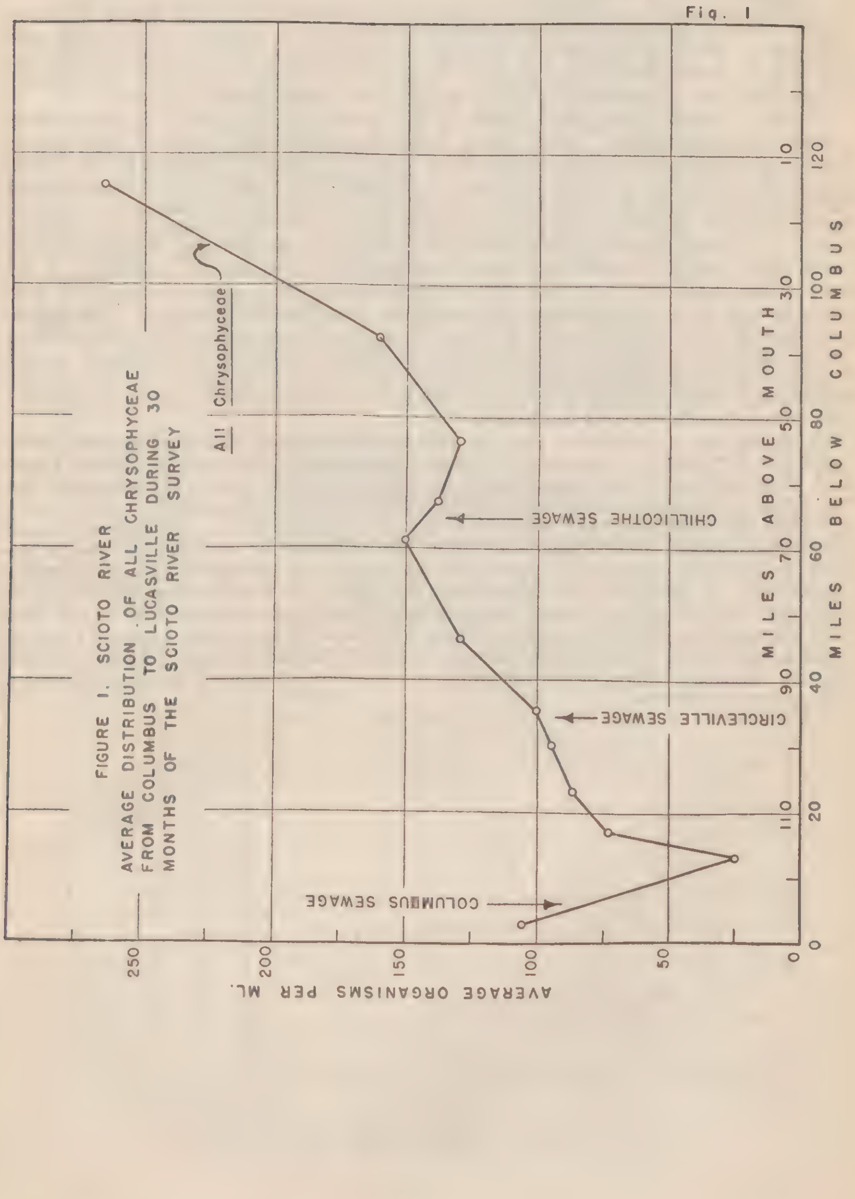
Fig. I
FIGURE I. SCIOTO RIVER
AVERAGE DISTRIBUTION OF ALL CHRYSOPHYCEAE
FROM COLUMBUS TO LUCASVILLE DURING 30
MONTHS OF THE SCIOTO RIVER SURVEY
All Chrysophyceae
COLUMBUS SEWAGE
CIRCLEVILLE SEWAGE
CHILLICOTHE SEWAGE
AVERAGE ORGANISMS PER ML.
MILES ABOVE MOUTH
MILES BELOW COLUMBUS
0
50
100
150
200
250
110
90
70
50
30
10
20
40
60
80
100
120

Only two whole groups of organisms, the *Chrysophyceae* or yellow flagellates, and the *Cryptophceae*, or olive-green flagellates, behaved as shown in figure 1, in the Scioto. In other groups, individual species or genera showed diverse reactions. Figure 2 shows the behavior of one genus and two species of diatoms (*Bacillarieae*). *Asterionella formosa* reacts adversely to sewage pollution; *Nitzschia acicularis*, while at least indifferent to the degree of pollution at Shadeville, still thrives best in clean water. *Navicula spp*, however, shows a great increase in the polluted zone, which is apparently reflected by the less degrees of pollution at Circleville and Chillicothe.

It is a virtual impossibility to distinguish the species of this genus in survey work. But it has been well established, by Kolkwitz (4) and others, that some species of *Navicula* apparently prefer polluted water, while others attain their maximum development elsewhere. Such a polymodal curve as in Figure 2 might well result from counting two or more indistinguishable species.

Figure 3 shows the distribution in the Scioto of a typical organism which favors sewage-polluted water as a habitat—*Sphaerotilus natans*, the sewage fungus. Figure 4 shows the behavior of certain species of *Euglena* in the Scioto. As a rule, members of this genus tend to be abundant only when the temperature is high, hence these average figures for all months of the year are low. Figure 4 includes those members of the genus which tend to be most abundant in polluted water. *Euglena oxyuris* apparently favors organic pollution also, but its members were rarely large. Conversely, some members of the genus, *E. mutabilis*, *E. spirogyra*, are rarely, if ever, found in polluted water, while great blooms of *E. polymorpha* and *E. sanguinea* have been noted in unpolluted situations. The highest averages for the species shown in Figure 4, however, are not in the badly polluted zone but in river stretches where there has been an increase in dissolved oxygen, with a drop in biochemical oxygen demand and coliform counts. In other words, the highest numbers tend to appear in the zone of nitrogenous oxidation and not in the zone of carbonaceous oxidation.

It is perhaps unfortunate that, in this biological study, conclusions are drawn from the distribution of suspended forms almost to the exclusion of bottom forms, but physical limitations compelled this. There is little doubt, for example, that the peak of the diatom *Navicula* at Shadeville is influenced by the numbers swept off the bottom of the very large riffle just above this point. Riffles tend to be liberally carpeted with diatoms at times, and since some of them are swept into suspension by the current, a peak such as the one at Shadeville could be misinterpreted. It could be due entirely to the fact that the physical nature of the substrate at that point favored the growth of diatoms and the current swept them into suspension, where they were readily available for counting, whereas both the mud bottom and decreased current at a lower station militated against a high count. In such a case, pollution might not even be a factor in the distribution of this genus of diatoms.

Fig. 2

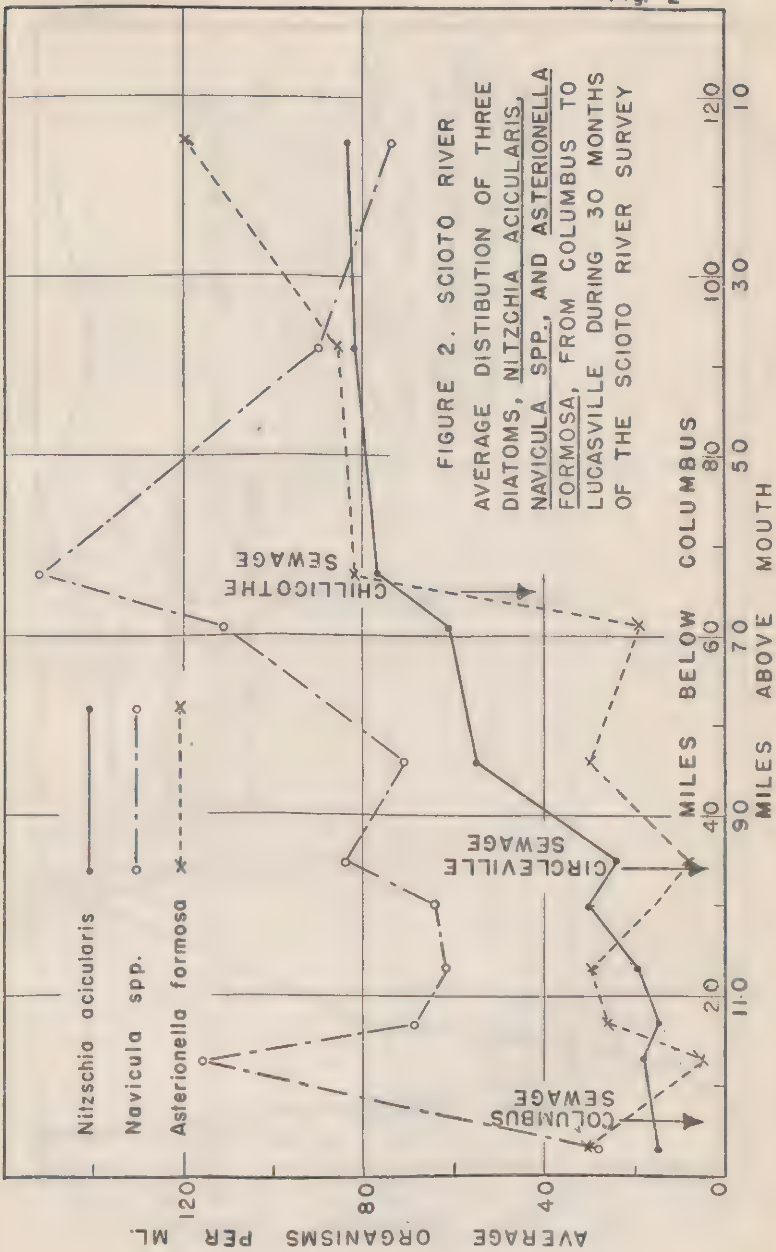

FIGURE 2. SCIOTO RIVER
AVERAGE DISTIBUTION OF THREE DIATOMS, NITZCHIA ACICULARIS, NAVICULA SPP., AND ASTERIONELLA FORMOSA, FROM COLUMBUS TO LUCASVILLE DURING 30 MONTHS OF THE SCIOTO RIVER SURVEY

Fig. 3

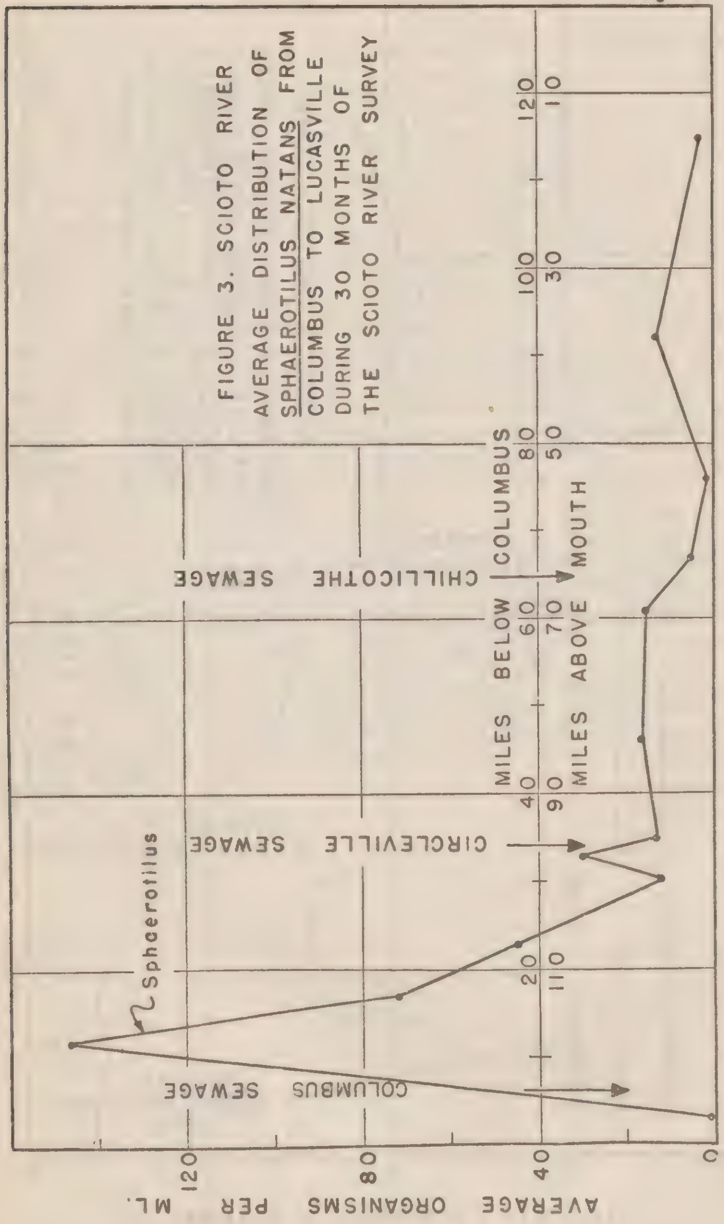
FIGURE 3. SCIOTO RIVER
AVERAGE DISTRIBUTION OF
SPHAEROTILUS NATANS FROM
COLUMBUS TO LUCASVILLE
DURING 30 MONTHS OF
THE SCIOTO RIVER SURVEY
MILES BELOW COLUMBUS
MILES ABOVE MOUTH
COLUMBUS SEWAGE
CIRCLEVILLE SEWAGE
CHILLICOTHE SEWAGE
Sphaerotilus
AVERAGE ORGANISMS PER ML.
120
80
40
0
20
40
60
80
100
120
110
90
70
50
30
10

Fig. 4

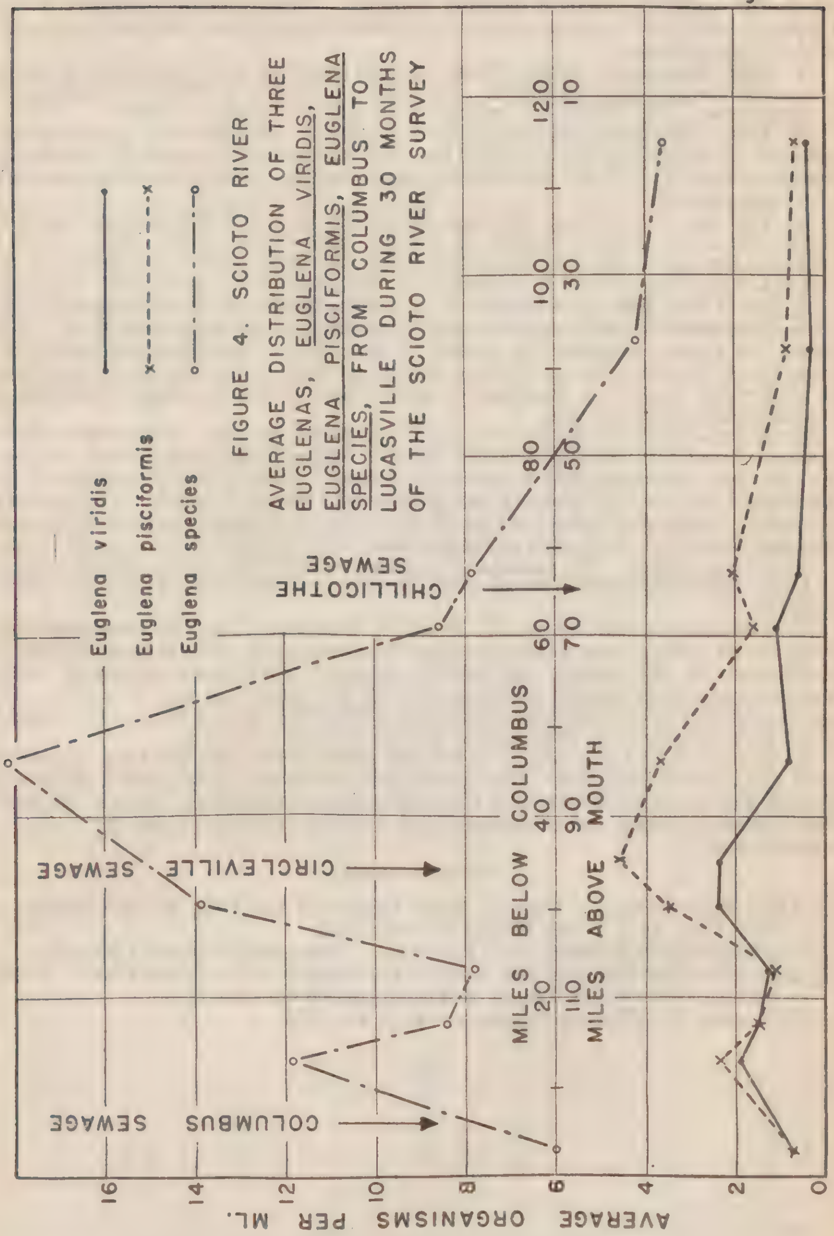

FIGURE 4. SCIOTO RIVER
AVERAGE DISTRIBUTION OF THREE EUGLENAS, EUGLENA VIRIDIS, EUGLENA PISCIFORMIS, EUGLENA SPECIES, FROM COLUMBUS TO LUCASVILLE DURING 30 MONTHS OF THE SCIOTO RIVER SURVEY

Conclusions

While the many factors influencing biological life demand extreme caution in the interpretation of results, certain facts seem fairly well established.

(1) Some organisms tend to be abundant, in their season, in river stretches where the water is of good sanitary quality. These include members of the *Chrysophyceae*, the *Cryptophyceae*, a few *Chlorophyceae*, some diatoms, and a few of the ciliate protozoa.

(2) Other organisms, notably fungi, certain bacteria, some species of *Euglenophyceae*, some species of *Volvocales*, and ciliates generally, if present in abundance, in their season, are reasonably indicative of recent organic pollution.

(3) Many organisms, abundant in sewage-disposal plants or foul pools, are not common to the Scioto at any point, but their absence may be due to insufficient organic pollution, or to the fact that they are primarily bottom-dwelling, creeping, or crawling forms.

(4) The vast majority of plankton organisms in the Scioto are not found in either the most polluted section or the cleanest section of the river. This is probably not due to any specific ecologic factors in these regions, but rather to the fact that these organisms are tolerant of a wide range of environment. It should be apparent that either gross pollution or extreme purity of water represent much more circumscribed environments than the region in between these two. This region, of course, includes the region of nitrogenous oxidation, but laboratory experiments for the most part fail to show any marked dependence of organisms of this region upon the existence of other than extremely small quantities of available oxidizable nitrogen.

(5) A well-defined seasonal succession is apparent for many of the Scioto River species. Some are most abundant in winter, others in the spring, but the great majority are most abundant in the later summer. This is far more apparent for phytoplankton than for zooplankton, as shown by figures 5 and 6. This seasonal succession is probably influenced by dilution, clarity of water, increased illumination and other factors, as well as temperature, but too much stress cannot be laid on any single factor. For example, the same seasonal succession occurs in pools or lakes, where clarity due to silt and dilution vary but little during the yearly cycle.

(6) Plankton production in the Scioto is extremely high, as compared with other rivers which have been investigated. Inevitably this is due in part to fertilization by the organic (and other) wastes of its densely populated basin, but there are other factors which cannot be discounted, as age of water. Nor can the fact be discounted that enormous, if transient, populations occur in pools which receive almost no drainage, or known organic pollution.

(7) More species have been found in the Scioto than reported from any other river in available literature. The species list is believed to be fairly comprehensive, as well as representative for rivers of a comparable class. In part at least. the increased species list is believed due to improvement in the technique of examination.

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(4) Kolkwitz, R. Pflanzenforschung. Heft 21, 1938.

Fig. 5

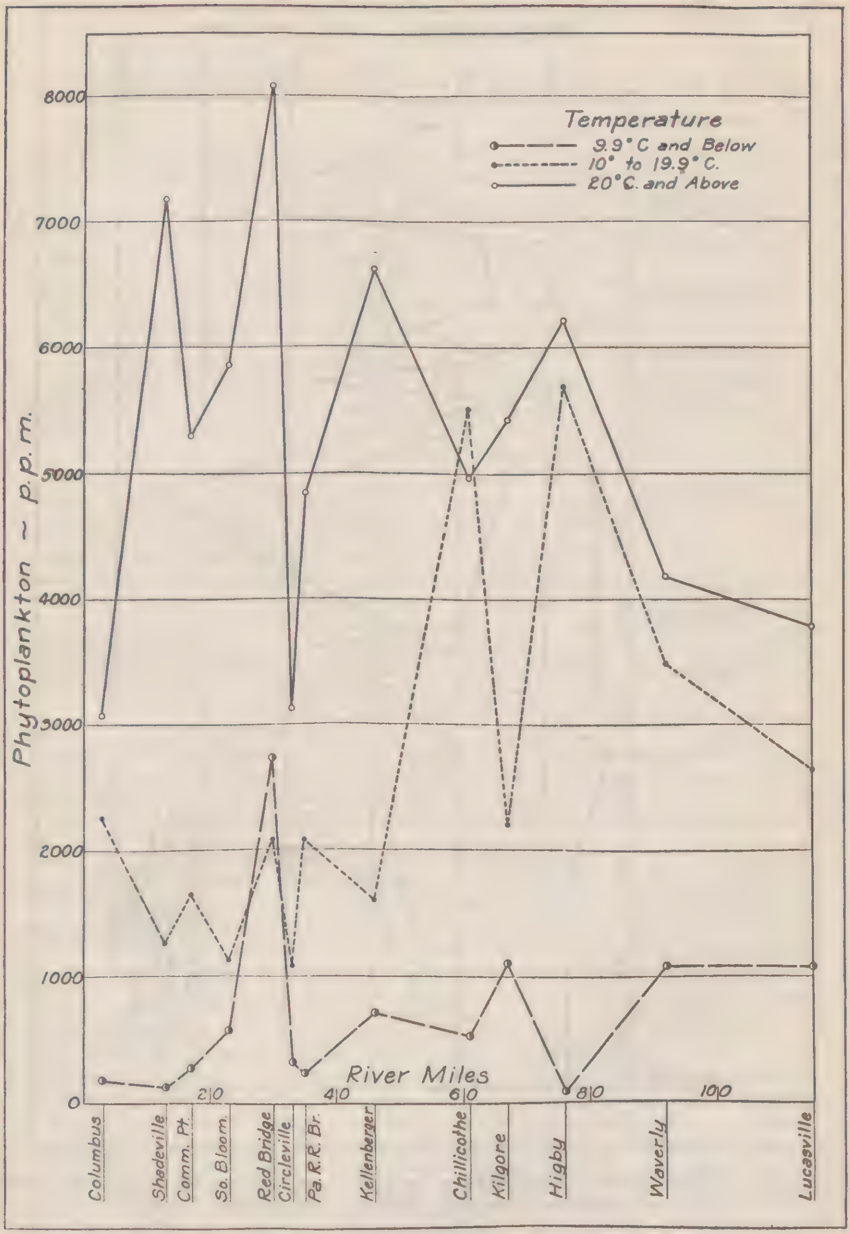

FIGURE 5.—Scioto River—Phytoplankton in parts per million by volume at each station during low flows for the three temperature ranges.

Fig. 6.

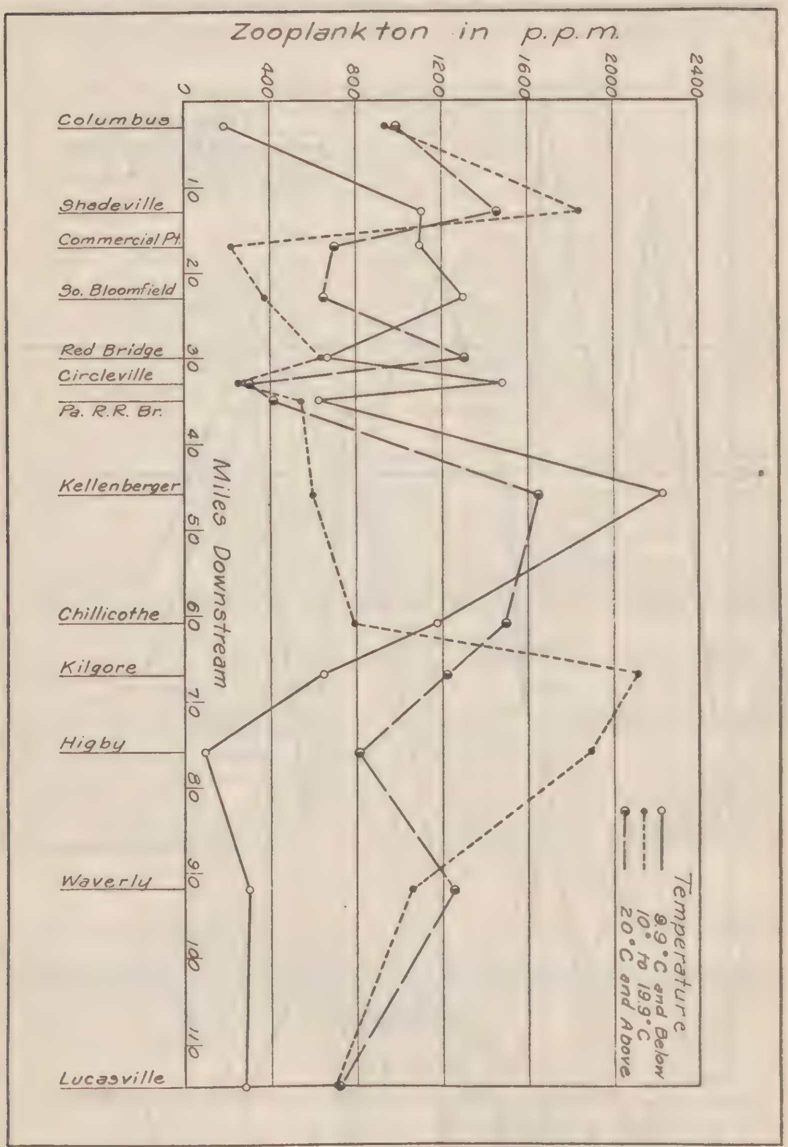

FIGURE 6.—Scioto River—Zooplankton in parts per million by volume at each station during low flows for the three temperature ranges.

APPENDIX II

DISCUSSION OF THE BIOLOGY AND POLLUTION OF THE TENNESSEE RIVER [1]

The Tennessee River receives run-off from an area of 40,600 square miles, draining portions of the following seven Southern States: Virginia, North Caroline, Tennessee, Georgia, Alabama, Mississippi, and Kentucky. The character of the valley varies from the steep forested slopes of the pre-Cambrian formations in the east, through the gently rolling calcareous deposits of the Cambrian in the main valley to the Pennsylvanian of the Cumberland Plateau. The run-offs from each of these areas have a decided effect upon the general appearance, biology, and mineral constituents of the Tennessee River and its tributaries.

The river itself is rapidly becoming a chain of impounded lakes or reservoirs from its mouth to Knoxville, 650 miles upstream. Seven of the nine run-of-the-river dams are in service and the two remaining dams, the Kentucky Dam near the mouth and Fort Loudoun Dam just below Knoxville, are under construction. There are now 13 Tennessee Valley Authority-operated dams on the tributaries which provide storage as well as additional power. Five more such dams are under construction. In addition to these, there are 6 major privately owned and operated hydroelectric plants and a number of smaller developments (see attached map of the Tennessee River system). Such developments forming reservoirs in a normally free-running stream are accompanied by a series of biological readjustments to the change from lotic to lenitic conditions.

Another factor having a direct bearing upon the biology of the Tennessee River system is the pollution received from the municipalities, industries, and the organic matter and silt washed from the land itself. In general, the area is predominantly rural, having but few large cities. The three largest cities—Chattanooga, Knoxville, and Asheville—account for approximately one-half of the sewered population of about 590,000. It is estimated that about 20 percent of the domestic sewage receives treatment and that much of this treatment is ineffective due to obsolete and overloaded plants. There are now a few highly developed industrial areas, chiefly in the eastern section of the valley. The industrial activities, however, are becoming more numerous and widespread due to the large amount of available power, raw materials, and to the need of additional capacity of plants producing essential war materials. There are perhaps three main types of wastes now present as classified by their effect upon the aquatic life.

The first type of waste consists of those exerting an oxygen demand on the stream. In the normally clean streams in the valley the ratio of the amount of dissolved oxygen to the 5-day bilchemical oxygen demand may at times exceed seven. This ratio decreases as pollution is added, passing Streeter's limit of one, which is considered necessary for the maintenance of favorable conditions, to reach a very low value in the more polluted sections. The sections in the main river below Knoxville and Chattanooga are polluted by domestic sewage and industrial wastes. The dissolved oxygen-biochemical oxygen demand ratio for the section below Knoxville has fallen below one for short periods of low flow but below Chattanooga it has remained well above this value.

The French Broad River below Brevard is highly colored and polluted by paper-mill wastes. Here the dissolved oxygen-biochemical oxygen demand ratio was found to be slightly more than one, but the color persists for a considerable distance downstream. At Asheville, the stream receives domestic sewage and the industrial wastes from a large viscose rayon plant. The rapid turbulent flow below this point results in a high dissolved oxygen-biochemical oxygen demand ratio. The river receives another large load of pollution from the Pigeon River, originating at a pulp and paper mill at Canton, N. C. This stream is

[1] Prepared by Biological Readjustment Division and the Health and Safety Department of the Tennessee Valley Authority, July 1942.

black all the way to its mouth, and contains less than one part per million of dissolved oxygen, even below Waterville Lake. The effect on the French Broad is to lower the dissolved oxygen-biochemical oxygen demand ratio to about 1.5 just below the mouth of the Pigeon River and to color the entire river from that point to its mouth.

Beaver Creek receives a heavy load of untreated domestic sewage and the industrial waste from a paper mill at Bristol. This stream is dark-colored even at its mouth and is septic in stretches, but near its mouth has a dissolved oxygen-biochemical oxygen demand ratio well above one; however, it does influence the South Holston into which it discharges by reducing the ratio from around seven to less than two at critical periods. At Kingsport the South Holston again receives domestic sewage, and industrial wastes from a large chemical and acetate-cellulose plant and a paper mill. Below these wastes the ratio is consistently below one during the summer season, and the stream does not entirely recover before it enters Cherokee Reservoir 35 miles below.

Emory River at Harriman, Tenn., receives the untreated domestic sewage from that town, wastes from a hosiery mill and from a paper plant. The ratio of dissolved oxygen-biochemical oxygen demand is reduced by these wastes from about 10 to less than 1 and the black color extends down this arm of the lake to the main body of Watts Bar.

Scott Creek receives a heavy load of industrial wastes from a tannery and paper mill at Sylva, N. C. It is highly colored and almost devoid of oxygen and seriously affects the Tuckasegee River. The dissolved oxygen-biochemical oxygen demand ratio of this stream 20 miles below Scott Creek is less than one, and the wastes color the Little Tennessee River, into which the Tuckasegee River discharges, from that point to its mouth.

This briefly describes the most important sections polluted by type 1 wastes. The second type consists of those wastes which materially lower the pH of the waters. In this classification belongs the drainage from the abandoned coal mines of the Cumberland Plateau. The waters of the Clinch and Powell River systems, draining such wastes, are highly acid until they leave the Pennsylvanian region and enter the Cambrian where the acid is neutralized by the lime formations. Another stream which is highly acid, due however to the wates discharged from a copper refining plant, is the Ocoee River. The pH of this stream has been as low as 4.5 at times.

The third group is chiefly composed of silt and minerals in suspension. Most of the streams draining the more developed areas carry considerable amounts of silt. However, there is one stream, the Tuck River, which receives large amounts of silt from the phosphate washing plants near Columbia, Tenn. It has been reported that this material has at times killed large numbers of fish.

The Tennessee River has a high biological productivity, as is evidenced by the qualitative and quantitative abundance of its fishes. With the impoundment of the main stream reservoirs, the production of fish has been greatly increased. Standing populations of over 800 pounds per acre have been recorded on the lower reservoirs. A valley-wide survey of fishes has to date taken 83 genera, containing 174 species comprising 186 forms. These include 12 species of game fishes, 11 species of pan fishes, 10 species of food fishes, and 18 common species of coarse fishes, as well as many other species of coarse and forage fishes. These fishes are important to the valley from a recreational, economic, and public health or nutritional standpoint. A census conducted in 1940 showed that commercial fishing with set lines yielded well over a million pounds in the four lower reservoirs alone. This fishery supported wholly or in part over 1,300 people on the three lower reservoirs. Fishermen counts made in 1940–41 indicate that the four lower reservoirs annually supported 1,200,000 man-days of fishing, a large part of which was fishing for food. Thus the fisheries of the valley constitute a valuable source of meat and play an important role in the nutrition and health of the people of the valley.

In comparison with other rivers of comparable size, the lower portion of the Tennessee River is relatively free of pollution, the most serious effects of pollution being largely confined to the main tributaries in the upper end of the valley. The biological effects of pollution of the Tennessee River may in general be attributed to the three types of pollutants previously described: (1) Those which bring about oxygen depletion and eliminate all organisms except those which can survive under anaerobic conditions; (2) Those which produce excessive acidity or otherwise directly toxic conditions and thereby eliminate all fish and other dominant organisms; (3) those which bring about an excessive amount of silting and decrease or eliminate aquatic life through the mechanical effects of smothering and the destruction of the natural habitat.

An outstanding case of the effects of gross pollution on the Tennessee watershed is that of the Pigeon River. The effluent from a large paper mill enters the headwaters of this stream. All fish life has been eliminated for a distance of approximately 25 miles, and the bottom fauna confined to those forms which can live under anaerobic conditions. In the remaining distance of about 40 miles to the junction with the French Broad River, the bottom fauna and the fish life is confined to a few species which are tolerant to pollution. Carp, common suckers, and a few minnows are the only species left of a once rich fish fauna. This condition prevails even though the stream drops 1,300 feet in the last 40 miles and receives abundant aeration.

Hyperacidity due to coal-mine wastes has totally destroyed the fish life and insect fauna in some of the streams tributary to the Emory and Clinch Rivers.

Silting in the Ocoee River due to mine waste and erosion has filled pools, covered riffles, and destroyed many fish-producing areas.

The reservoirs of the Tennessee System may in general be divided into two types, tributary reservoirs and run-of-the-river reservoirs.

The tributary reservoirs are located on tributary streams in the upper part of the valley. They have a decided chemical and thermal stratification and little river influence, because of the relatively large storage volume in comparison to the inflow. Also, these reservoirs are usually characterized by the formation of density currents which at times cause a rather complex stratification (Wiebe, 1940). They usually have one major fluctuation each year, the water level being high during the spring and summer and low during the fall and winter, water levels frequently varying as much as 100 feet during the year.

Because of the clearness of the water and the typical lenitic conditions produced by storage of practically all inflow during the spring and summer months, the tributary reservoirs have a higher population of plankton than the run-of-the-river reservoirs. Due to the wide annual fluctuation, the acquatic vegetation which normally occupies the littoral zone of lakes is absent from these reservoirs, and the bottom fauna is greatly reduced. Such bottom fauna as is present is largely confined to the hypolimnion and is mainly restricted to such forms as oligochaet worms, chironomids, and Chaoborus, which can exist under the anaerobic conditions which frequently occur there.

The fish population of the tributary reservoirs differs from that of the run-of-the-river reservoirs in having a higher relative abundance of game species but a lower total population in pounds per acre. Because of the clear waters, small-mouth bass, black crappie, and wall-eyed pike predominate.

The run-of-the-river reservoirs are located along the main channel of the Tennessee River. In general these reservoirs may be divided into three sections: an upper third where the water is confined primarily to the original channel; a middle third where the water overflows the original banks (natural levees) of the stream; and a lower third where the lake extends to the fairly steep margin of the river flood plain. Because of their relatively small volume in relation to inflow and outflow, river conditions predominate and there is seldom any chemical or thermal stratification. In addition, the water of these reservoirs is generally more turbid than that of the tributary reservoirs, becoming quite muddy during flood conditions.

Under normal conditions, in the upper sections of these reservoirs there is always a perceptible current and the water is more turbid than in the lower sections; likewise, each reservoir is generally less turbid than the one next above it and silting is correspondingly reduced. The over-all fluctuation of water level is much less than on the tributary reservoirs, usually ranging from 2 to 10 feet in different reservoirs. In summer there are frequent minor fluctuations in water level coupled with a gradual seasonal drawdown extending into the winter period. Turbidity, fluctuation, and other factors such as the activity of certain coarse fishes, greatly inhibit the growth of aquatic vegetation.

The plankton population of the run-of-the-river reservoirs is highest in the clear water of the low sections, and is lowest in the upper sections where current and turbidity are more pronounced. In general, in passing from one reservoir to the next lower, an increased production of plankton is correlated with the decreased turbidity. The greatest production of plankton occurs during the early winter when the flow is largely composed of clear water from the tributary reservoirs.

Bottom fauna is much more varied and abundant in the run-of-the-river than in the tributary reservoirs. The predominant forms in order of their relative abundance as determined by volume are Ephemeroptera, Chironomidae, Chaoborinae, and Oligochaeta. The mayflies, which consist chiefly of one species,

Hexagenia bilineata, reach their greatest abundance just below the lower limit of the zone of fluctuation, and in silty bottoms may extend to depths of 30 or more feet. The phantom midge, *Chaoborus*, and the oligochaet worms are largely confined to the deeper waters in the silted lower sections of the reservoirs. Chironomids are numerically more abundant than any other form and occur from the shallow to the deep waters. Certain of the smaller species are apparently well adapted for existence in the zone of fluctuation, where they reach their greatest abundance; other larger species attain their greatest abundance in the deeper waters of the lower sections of the reservoirs. In general, the forms which occupy the zone of fluctuation are those having a short life cycle or well-developed powers of locomotion. Among these the most important appears to be the corixid, *Trichocoriza burmeisteri*, which attains tremendous abundance in the shallow waters and constitutes an important item in the food of certain species of fish.

The standing population of fishes is much greater in the lower reservoirs than in the tributary reservoirs. Game fishes comprise a lower percentage of the total population than in the storage reservoirs because environmental conditions favor the coarse species.

Among the nine species of game fishes occurring in the lower reservoirs, largemouth bass, white bass, and the sauger are the most important in the order named. Pan fishes are numerically more abundant than the game fishes, and although 11 species occur in the area, crappie and bluegills comprise almost the total catch. The most important food fishes are the catfishes, drum, and the spoonbill sturgeon. A large number of coarse fish occur in the lower reservoirs, the most abundant being carp, buffalo, gizzard shad, and gar. In the backwater areas these coarse fishes may make up 70 to 85 percent of the weight of the total fish population.

The Tennessee River at its mouth is considered a clean stream. It is normally clear, has very low bacterial counts and biochemical oxygen demand, and the plankton are those usually observed in clear waters having very little organic material.

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